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ABSTRACT

Threat-related stimuli can capture attention. However, it remains debated whether this capture is automatic or not. To address this question, we compared attentional biases to emotional faces using a dot-probe task (DPT) where emotion was never goal-relevant (Experiment 1) or made directly task-relevant by means of induction trials (Experiments 2–3). Moreover, the contingency between the DPT and induction trials was either partial (Experiment 2) or full (Experiment 3). Eye-tracking was used to ascertain that the emotional cue and the subsequent target were processed with peripheral vision. Experiments 1 and 2 both showed that negative faces captured attention, with faster target processing when it appeared on the same side as the preceding fearful face (i.e. fear-valid trials) compared to the opposite side where the neutral face was shown (i.e. fear-invalid trials), but also when it appeared on the side of the preceding neutral face (i.e. happy-invalid trials) compared to the happy face (i.e. happy-valid trials). Importantly, this preferential spatial orienting to negative emotion was not observed in Experiment 3, where the goal relevance of emotion was high. However, in that experiment, fearful faces produced a specific attentional bias during the DPT, which was mostly driven by the induction trials themselves.

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Previous studies have shown that threat-related stimuli, such as fearful or angry faces, can capture attention (Pourtois et al., 2013; Vuilleumier, 2005; Yiend, 2010). This capture is usually shown by faster reaction times (RTs) and/or better processing (i.e. higher accuracy, ACC) for these threat-related stimuli compared to neutral or positive stimuli in various tasks and contexts, including visual search (Eastwood et al., 2001; Fox et al., 2000), attentional blink (Anderson & Phelps, 2001; Schwabe et al., 2011), cueing (Fox et al., 2001; Phelps et al., 2006), or dot-probe task (DPT) (Lipp & Derakshan, 2005; Mogg & Bradley, 1999). These results have been interpreted as reflecting the prioritised processing of threat-related stimuli, which influence the guidance and control of attention. Moreover, this influence of (negative) emotion on attention can be dissociated from the modulatory effects driven by either physical salience (i.e. bottom-up attention) or goals (i.e. top-down attention) (Awh et al., 2012; Pourtois et al., 2013; Sussman et al., 2016). More specifically, according to the contemporary notion of a priority map (see Ptak, 2012 for a review), not only physical salience and goals can determine the selection of specific stimuli or locations in the environment, but also their emotional or motivational value, which can be either positive/reward-related (Anderson et al., 2011) or negative/threat-related (Carretié, 2014; Mulckhuyse, 2018). Accordingly, threat-related stimuli can capture attention because they shape and influence

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the priority map, besides physical salience and goals. However, an unanswered question is whether the capture of attention by threat is deemed automatic or not, especially when considered in relation to goals. Interestingly, some previous studies found that top-down attention driven by goals could impinge on the propensity of (negative) emotional stimuli to capture attention in a bottom-up manner, suggesting that goals could override emotional attention (Everaert et al., 2013). In agreement with this view, it was previously reported that (negative or aversive) emotional stimuli only captured attention when they were goal or task-relevant (Brown et al., 2020; Vogt et al., 2017). Likewise, it was found that the prioritised processing of threat-related stimuli was strongly reduced when goals or top-down attention was promoted (Cunningham et al., 2021; Stein et al., 2009; Yates et al., 2010).

According to a dominant theoretical model (Coltheart, 1999; Moors & De Houwer, 2006), automaticity should not be conceived as all-or-none or unconditional, but instead, it should carefully be assessed along several defining features (which moreover can be orthogonal to each other) in order to determine whether the process under consideration is eventually automatic or not. Among them, (un)intentionality, (un)controllability, goal independence, autonomy, stimulus-drivenness, consciousness, efficiency and speed have been put forward. In this study, we focused on goal independence as a distinctive feature of automaticity because it has gained traction in recent years (e.g. Brown et al., 2020; Moors et al., 2017; Vogt et al., 2017). Moreover, dominant models of selective attention reviewed here above assume that goal is an important drive for (target) selection and processing (besides physical salience and value; see Awh et al., 2012; Corbetta & Shulman, 2002). In addition, from a pragmatic angle, goal relevance can also be manipulated easily and directly, for example by using induction trials, thereby offering a powerful means at the methodological levels to study its impact on emotional attention in well-controlled experimental designs. To achieve this, we used and adapted the DPT, which is a classic paradigm to explore the capture of attention by (negative) emotion (Fox et al., 2002; Mather & Carstensen, 2003; Salemink et al., 2007; Wentura et al., 2024; Wirth & Wentura, 2020).

In this task, a pair of faces or words is briefly shown and used as a cue, before a unilateral stimulus (usually a dot, serving as a target) is shown, and participants are asked either to detect or discriminate it. Critically, one of the faces (or words) in the pair is neutral while the other one is emotional (e.g. threatening). Validity is defined by the common spatial location occupied by this emotional face (or word) and the subsequent target stimulus. Interestingly, the DPT can be combined with induction trials to assess whether emotional attention is automatic or not (Cunningham et al., 2021; Fournier & Koenig, 2023; Vogt et al., 2013, 2017). More specifically, besides the main DPT, a second task has to be performed by the participants on the cue, which in turn creates a specific top-down attention control set for this emotional stimulus used at the cue level (Banich et al., 2000). Using this methodology, previous studies (Vogt et al., 2013, 2017) reported that the capture of attention by negative emotion was not automatic but depended on these induction trials: this capture was larger when these threat-related stimuli were attended to or were task-relevant compared to a control condition where they were not (Brosch et al., 2011; Stein et al., 2009; Vogt et al., 2013).

Although these previous studies informed about the non-automaticity of emotional attention, an important question remaining pertains to the function of induction trials to change goal processing, which in turn should modulate emotional attention. Presumably, the actual task to be performed with these induction trials might determine the strength with which the corresponding goal is activated and how emotional attention is eventually altered. In this context, it is interesting to note that Vogt et al. (2013) used a simple detection task for them. In comparison, Stein et al. (2009) used either a gender or emotion discrimination task, while Fournier and Koenig (2023) used a more complex stimulus rating task along the intrinsic relevance, goal relevance and action tendency dimensions. Last, Brown et al. (2020) did not use the DPT but combined the emotion-induced blindness paradigm with contingent capture and manipulated search goals. We could imagine that the more proximal and explicit the task for the induction trials is in relation to the goal, the stronger the modulation of emotional attention by it. In a similar vein, the frequency of induction trials might spur the potency of the goal. If induction trials are frequent and systematic, then the goal is probably stronger than if they are deviant and lacking specificity. Accordingly, the frequency and systematicity of induction trials could turn out to be an important factor to consider when the modulation of emotional attention by goal relevance is considered. Moreover, at the methodological level, a possible limitation of these previous studies is that they did not measure eye movements (using eye tracking) and hence, they could not establish whether overt or instead covert shifts of spatial attention actually contributed to the reported emotional attention effects during the DPT. Because the target (as well as the preceding emotional face) is shown in the periphery with this task, in principle participants could move their eyes to this position to process it, which would correspond to overt attention. In comparison, covert attention implies that the emotional face and the target are processed using peripheral vision and without eye movements. Although overt and covert spatial attention share some common ground (Corbetta, 1998; Corbetta et al., 1998), they are not equivalent and accordingly, it appears important to control eye movements to assess whether the reported emotional attention effects are explained either by the former or latter spatial attention process.

In the current study, we sought to assess whether the frequency of induction trials could influence emotional attention or not. Moreover, we used eye-tracking to ascertain that covert shifts of spatial attention occurred during the DPT. We devised three experiments. In Experiment 1, the participants performed the DPT, without any induction trial, allowing us to assess whether fearful faces could capture attention or not in these conditions (Lipp & Derakshan, 2005; Mogg & Bradley, 1999; Pourtois et al., 2004; Sutton & Altarriba, 2011). In Experiments 2 and 3, the participants carried out the same DPT, however in combination with induction trials where they had to indicate the side (either left or right) occupied by the emotional face in the pair at the cue level. In Experiment 2, induction trials had a low probability (i.e. 20%), meaning that 20% of the trials were induction trials while 80% were dot probe trials, with these two trial types shown in a pseudo-random order (i.e. partial contingency). In Experiment 3, induction trials had a high probability (i.e. 100%), meaning that every dot-probe trial was preceded by an induction trial (i.e. full contingency). As a result of this manipulation, in Experiment 2, the effect of goal relevance was low (or partial) whereas it was high (or full) in Experiment 3. This enabled us to determine whether the capture of attention by fearful faces could be potentiated by the goal relevance of emotion (Brown et al., 2020; Vogt et al., 2013, 2017). Our hypothesis was that if fearful faces capture attention automatically (Dolan, 2002; Vuilleumier, 2005), then all three experiments should reveal faster RTs (as well as a higher ACC) for fear valid than fear invalid trials, without any corresponding validity effect (or alternatively, a reduced or even reversed one) for happy faces (i.e. interaction between Emotion and Validity). Alternatively, if the capture of attention by fearful faces is not automatic but is modulated by the goal relevance of emotion (Brown et al., 2020; Victeur et al., 2020; Vogt et al., 2013, 2017; Vromen et al., 2016), then a general validity effect for both fearful and happy faces could be observed in Experiments 2&3 because emotion (irrespective of valence) is goal relevant in them. Moreover, this validity effect could be stronger in Experiment 3 than 2 because the goal relevance of emotion is the highest in the former experiment.

Methods

Participants

The sample size was determined a priori using MorePower (Version 6.0). We used as prior the effect size (i.e. 0.22) for the significant interaction found between emotion and validity from our previous study (Xue & Pourtois, 2024, preprint). The significance level was set to 0.05 and a power of 90% was used. Using these parameters, the sample size was estimated to be 40. In total, 127 participants were recruited: 43 in Experiment 1, 42 in Experiment 2 and 42 in Experiment 3. The data of one participant in Experiment 1 were removed because of eye-tracking problems, and of another one because of excessively slow responses (i.e. falling three standard deviations (SDs) above the mean). The data of a third participant were also removed because he reported some physical symptoms in the middle of the experiment and did not feel well. In Experiment 2, the data of one participant were removed because of a lack of sleep the night before testing and of another one due to poor ACC (i.e. it fell three SDs below the mean). In Experiment 3, one participant was removed due to poor ACC with the main dot-probe trials (i.e. it fell below three SDs below the mean). Hence, the data of 121 participants were retained for further analyses (Experiment 1: 40 participants, aged 18–33, mean age = 21.73 years, SD = 3.42 years, 5 males; Experiment 2: 40 participants, aged 18–29, mean age = 20.78 years, SD = 2.81 years, 6 males; Experiment 3: 41 participants, aged 18–27, mean age = 19.03 years, SD = 1.88 years, 7 males). Participants were recruited online using Sona (https://www.sona-systems.com/), as administered by Gent University. They all were right-handed and had normal or corrected-to-normal vision, no history of neurological or psychological impairment, and no current medication. All participants provided written informed consent and were compensated 10 euros for their participation. The study was approved by the local ethical committee of the faculty of psychology and educational sciences at Ghent University (file number: #2022-029).

Apparatus and stimuli

Participants were seated approximately 70 cm away from a 19-inch CRT screen with 1024 × 768 resolution (60 Hz), with their head restrained by a chinrest in a soundproof experimental room. Stimulus presentation and response recording were controlled by E-prime (Version 3.0). For the responses, a response pad was used. The position of the left eye was monitored continuously using an Eyelink 1000+ eye-tracking system (SR Research) at a sampling rate of 1000 Hz. We used specific E-Prime Extensions for Eyelink to synchronise stimulus presentation with this eye-tracking device. A 9-point calibration procedure was used at the beginning as well as in the middle of the experiment.

As stimuli, we used the emotional faces from the Ekman dataset (Friesen & Ekman, 1976) and selected 10 distinct identities (5 males and 5 females). For each of them, fearful, happy and neutral facial expressions were selected, resulting in a set of 30 different face stimuli. Each face was trimmed to remove the hair, ears, neck and non-facial information by an oval shape measuring 6 × 8 cm and was converted to greyscale. Each face stimulus was adjusted in ImageJ. A non-parametric analysis (based on a Kruskal–Wallis test) showed that the mean luminance and contrast were not statistically different between the three emotion categories [luminance: $H(2) = 2.821$, $P = 0.244$; contrast: $H(2) = 1.506$, $P = 0.471$].

We constructed 160 pairs of faces and used them as cues during the DPT. Each pair was composed of two different identities with the same gender. One face in the pair had an emotional expression (either fearful or happy) while the other one was neutral. Each face was positioned 8 cm away from the fixation cross (1 × 1 cm) along the horizontal axis, with one of them on the left side and the other one on the right side. Four different combinations of faces were created to yield an equal number of neutral and emotional faces on both sides: fearful-neutral, neutral-fearful, happy-neutral and neutral-happy. For each combination, 40 different pairs were created.

After the cue, a unilateral target measuring 3 × 3 cm was presented. It corresponded to a square (dark grey colour with hex code #131313) that could be titled 45 degrees clockwise and become a diamond. Hence the target was either a square or a diamond. On each side of the screen, two (white) placeholders were presented along with the (unilateral) target. They were used to increase target processing at the places where the two faces were previously shown. These placeholders corresponded to square brackets and their size was 6 × 8 cm, which was the same as the faces presented at the cue level. Because the background was black (and uniform) and the target was grey, the latter had low contrast and hence spatial attention had to be oriented (covertly) to its location in order to process its shape (either square or diamond). Each type of target (either square or diamond) was shown with an equal probability at each of the two locations (either left or right side).

Procedure

All stimuli were shown on a black background. Experiment 1 consisted of one practice block of 20 trials, followed by 8 experimental blocks of 80 trials (a total of 640 trials). In Experiment 2, each block included 100 trials (i.e. 80 dot probe trials as in Experiment 1, plus 20 induction trials, shown in a pseudo-random order; see here below), amounting to 800 trials. In Experiment 3, each block included 80 trials (i.e. 40 dot probe trials plus 40 induction trials; each DPT trial was preceded by an induction trial), yielding 640 trials in total.

For the main DPT (see Figure 1A), each trial began with a fixation cross shown for 500 ms, followed by the cue (i.e. a pair of faces) shown for 100 ms. After a short, variable, and equiprobable interval (i.e. 100, 150, 200, 250, or 300 ms), the target was presented for 150 ms. These parameters were used to prevent temporal attention effects and in agreement with a previous study (Pourtois et al., 2004). A trial was coded as valid if the target replaced the position of the emotional face (either a fearful or a happy face) and invalid if it replaced the neutral face. Accordingly, there were four main conditions (see Figure 1C): fear-valid, fear-invalid, happy-valid and happy-invalid, with

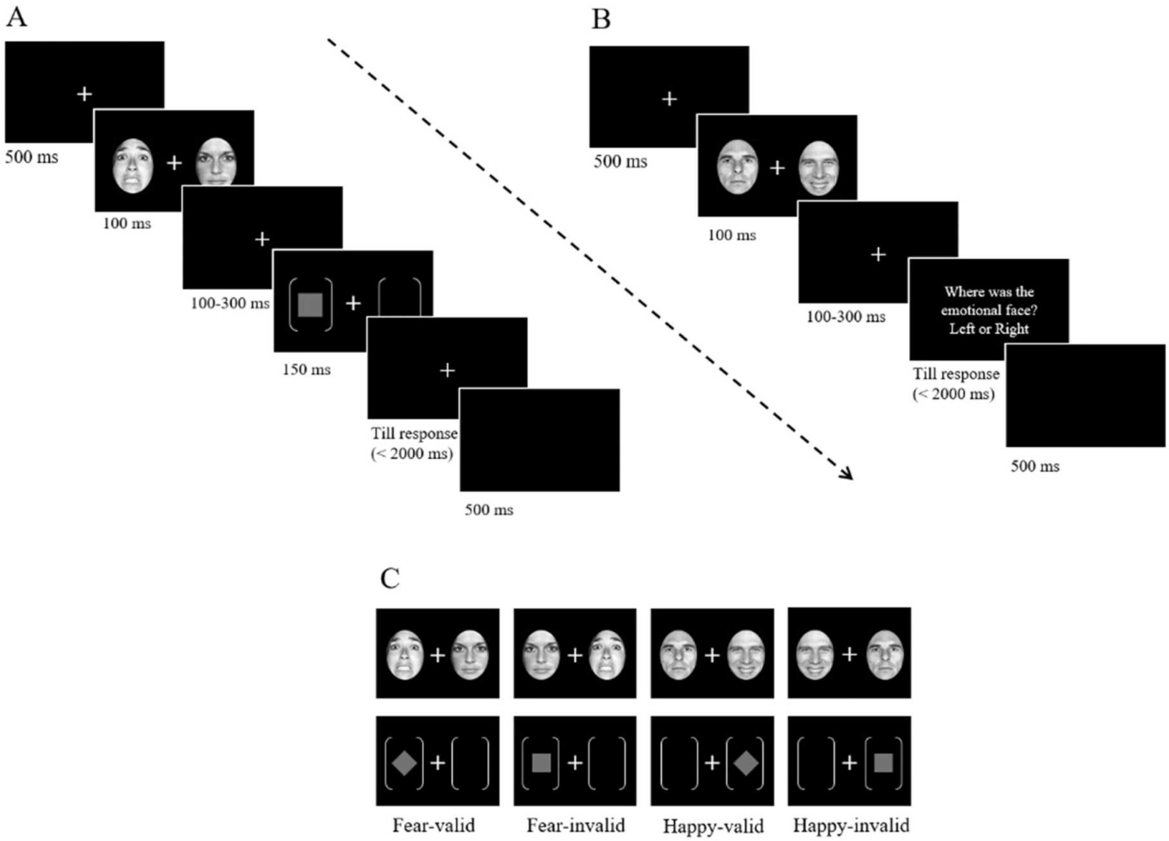

Figure 1. (A) Structure of a DPT trial (here fear valid) as used in Experiments 1, 2 and 3. (B) Structure of an induction trial (here the emotional face, fearful face, is shown on the left side) as used in Experiments 2 and 3. (C) Examples of the four main conditions used during the DPT.

an equal number of valid and invalid trials. Participants were asked to discriminate the shape of the target, either a diamond or a square, as quickly as possible. Speed was emphasised. In Experiment 1, participants used their left index finger for the diamond and their right index finger for the square or vice versa. In Experiments 2 and 3, because of the induction trials (see here below), participants had to use their right index finger for the diamond and right middle finger for the square or vice versa. The duration of the inter-trial interval was 500 ms.

In Experiments 2 and 3 (see Figure 1B), for the induction trials, following the presentation of the cue (100 ms) and after a varying interval (100, 150, 200, 250, or 300 ms), a response screen appeared. Participants were asked to discriminate the location (either left or right) of the emotional face shown at the cue level. To this end, they had to use their left index (for the left side) or left middle finger (for the right side). What differed between the two experiments was contingency, which was either low (Experiment 2) or high (Experiment 3). In Experiment 2, 20 induction trials were pseudo-randomly interspersed with the 80 DPT trials. As a rule, we used a minimum of two and a maximum of six successive DPT trials to ensure that there were no repetitions of induction trials. This rule was used in each block. In Experiment 3, contingency was high because each DPT trial was preceded by an induction trial. The participants were informed about this procedure and order.

Data analysis

Data analyses were conducted with Matlab R2023a (The Mathworks Inc., Natick, MA, USA). To ensure that participants processed all stimuli with peripheral vision, we removed offline the trials where the eye deviated more than 3 degrees away from the central fixation cross (see Figures S2–S4; supplementary materials).

ACC and RTs for correct responses were analysed using JASP (version 0.17). Data visualisation was carried out in R Studio (3.3.0), using the ggplot2 package. For ACC, for each participant separately, the first trial of each block and outliers (defined using a ± 3 SDs criterion above/below the grand mean) were excluded. For the RT data, the first trial of each block, incorrect trials and outliers were excluded from further analyses. Then, two-way repeated-measures ANOVAs with Emotion and Validity as a within-subject factor were performed in Experiments 1 and 2 for ACC (see supplementary materials) and RTs separately. In Experiment 3, two four-way repeated-measures ANOVAs with Emotion, Validity, Emotional compatibility and Spatial compatibility as a within-subject factor were performed. Emotional compatibility referred to the overlap between the spatial position occupied by the emotional face (either fearful or happy shown either on the left or right side) in the induction trial and that of the emotional face shown subsequently at the cue level during the DPT (either left or right side), or the lack thereof. Spatial compatibility corresponded to the overlap between the spatial position occupied by the emotional face in the induction trial and the subsequent target's location (either left or right), or the lack thereof. Because induction trials with incorrect responses could indicate that the participants did not process emotion at the face pair level correctly and/or did not pay attention to it (which would reduce the potency of the goal relevance manipulation), we re-analysed the data of Experiment 3 after we had excluded them (see Figure S1, supplementary materials). Last, we performed a combined statistical analysis where Experiment was added as a third between-subjects factor to assess whether the attentional bias towards fearful faces changed depending on goal relevance or not.

For completeness, we also computed attentional bias scores (ABSes) by subtracting invalid from valid trials for ACC, and valid from invalid trials for RTs (see supplementary materials). A positive score indicates (enhanced) orienting to the emotional face while a negative score indicates (enhanced) orienting to the neutral face in the pair. Simple t-tests were performed to investigate whether the ABSes differed from zero.

We report partial eta square (η_p^2) values as an estimate of effect size. A Bonferroni correction was used for post-hoc comparisons. For all these analyses, the significance level was set to $p < 0.05$, and Bayes factors were calculated using a default prior effect size based on a Cauchy distribution with a scale parameter of 0.707, as implemented in JASP (version 0.17), enabling us to quantify the amount of evidence gathered in favour of the null (H_0) or the alternative hypothesis (H_1).

Results

Experiment 1

For the RTs (see Figure 2B), the ANOVA showed significant main effects of Emotion ($F_{1,39} = 4.413$, $p = 0.042$, $\eta_p^2 = 0.102$) and Validity ($F_{1,39} = 6.292$, $p = 0.016$, $\eta_p^2 =$ 0.139). Moreover and importantly, the interaction between Emotion and Validity was also significant ($F_{1,39} = 32.731$, $p < 0.001$, $\eta_p^2 = 0.456$). Post-hoc t-tests showed faster RTs for fear-valid than either fear-invalid ($t_{39} = -2.158$, $p = 0.068$, Cohen's $d = -0.067$) or happy-valid trials ($t_{39} = -3.276$, $p = 0.006$, Cohen's $d = -0.088$). Happy-invalid trials were also faster than fear-valid ($t_{39} = 3.265$, $p = 0.006$, Cohen's $d =$ 0.090), fear-invalid ($t_{39} = 5.823$, $p < 0.001$, Cohen's d $= 0.157$) or happy-valid trials ($t_{39} = 5.774$, $p < 0.001$,

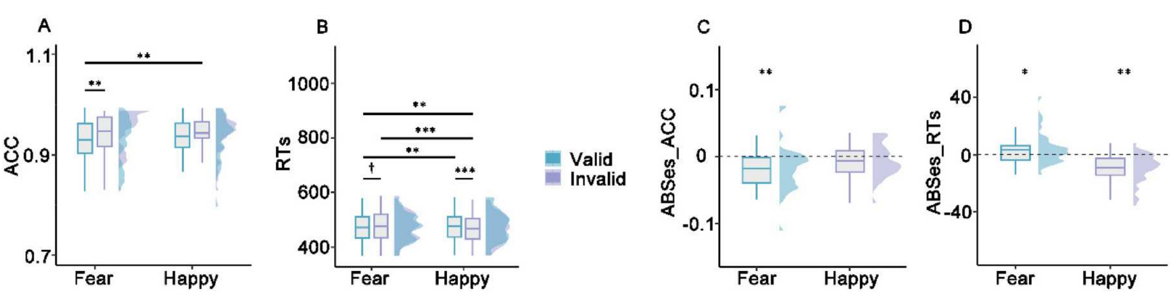

Figure 2. Results for the DPT in Experiment 1. In each graph, the mean performance is shown in a boxplot along with their distribution (half-density with colour).

Cohen's $d = 0.179$). The Bayesian ANOVA indicated anecdotal evidence for including the main effect of Validity ($BF_{incl} = 1.475$), decisive evidence for including the interaction between Emotion and Validity ($BF_{incl} = 2.527 \times 10^{+7}$), and anecdotal evidence against including the main effect of Emotion ($BF_{incl} = 0.453$).

Experiment 2

For the induction trials, the mean ACC was 67.9% (SD = 0.106) and the mean RT for correct responses was 892 ms (SD = 158.389). The mean ACC for fearful-neutral and happy-neutral pairs was 67.3% (SD = 0.111) and 68.6% (SD = 0.119), respectively (see Figure 3A). They were not statistically different from each other ($t_{39} = 0.928$, $p = 0.359$, Cohen's $d = 0.147$). The mean RTs for fearful-neutral and happy-neutral pairs were 901.973 (SD = 150.742) and 884.655 ms (SD = 173.416), respectively (see Figure 3C). They did not differ from each other either ($t_{39} = 1.681$, $p = 0.101$, Cohen's $d = 0.266$).

For the RTs during the DPT (see Figure 4B), the ANOVA showed a significant main effect of Emotion

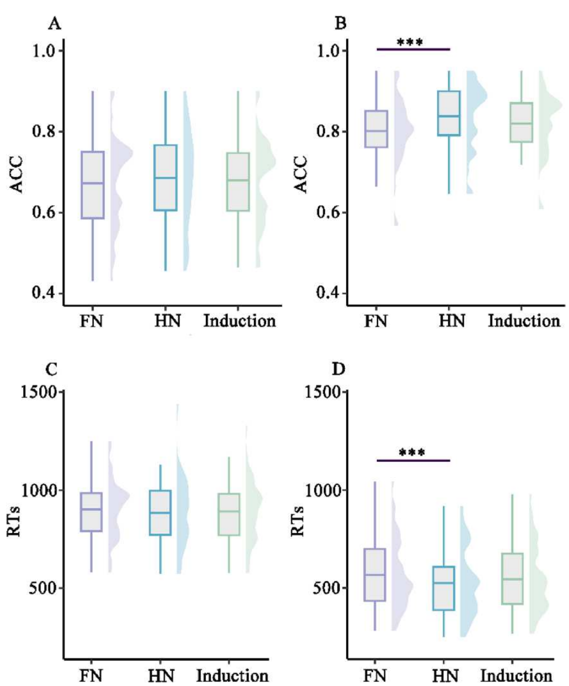

Figure 3. Results for the induction trials (Experiment 2 – left column and Experiment 3 – right column). (A & B) ACC and (C & D) RTs. FN refers to fear-neutral pair while HN to happy-neutral pair. Induction corresponds to the mean performance between these two conditions.

($F_{1,39} = 4.481$, $p = 0.041$, $\eta_p^2 = 0.103$), indicating faster RTs for happy trials compared to fear trials. Moreover, the interaction between Emotion and Validity was significant ($F_{1,39} = 31.511$, $p < 0.001$, $\eta_p^2 = 0.447$). Post-hoc tests showed faster RTs for fear-valid than fear-invalid trials ($t_{39} = -2.644$, $p = 0.040$, Cohen's $d = -0.104$). Moreover, RTs were faster for happy-invalid than either happy-valid ($t_{39} = -4.364$, $p < 0.001$, Cohen's $d = -0.172$) or fear-invalid trials ($t_{39} = -5.036$, $p < 0.001$, Cohen's $d = -0.209$). RTs were slower for fear-valid than the happy-invalid trials, although this effect was marginally significant only ($t_{39} = 2.302$, $p = 0.072$, Cohen's $d = 0.105$). The main effect of Validity was not significant ($F_{1,39} = 1.212$, $p = 0.278$, $\eta_p^2 = 0.030$). The Bayesian ANOVA provided anecdotal evidence for including the main effect of Emotion ($BF_{incl} = 1.120$), decisive evidence for including the interaction between Emotion and Validity ($BF_{incl} = 103783.751$), and moderate evidence against including the main effect of Validity ($BF_{incl} = 0.312$).

Experiment 3

For the induction trials, the mean ACC was 82.0% (SD = 0.076) and the mean RT for correct responses was 544.419 ms (SD = 172.172). The mean ACC for fearful-neutral and happy-neutral pairs was 80.1% (SD = 0.080) and 83.8% (SD = 0.084), respectively (see Figure 3B). They were statistically different from each other ($t_{40} = -3.503$, $p = 0.001$, Cohen's $d = 0.134$; $BF_{10} = 26.796$ suggesting very strong evidence), with higher ACC for happy-neutral than fearful-neutral pairs. The mean RTs for fearful-neutral and happy-neutral pairs were 566 (SD = 177.545) and 525 ms (SD = 170.964), respectively (see Figure 3D). They also differed from each other ($t_{40} = 5.157$, $p < 0.001$, Cohen's $d = 0.805$; $BF_{10} = 2718.382$ suggesting decisive evidence), with faster RTs for happy-neutral than fearful-neutral pairs.

For the RTs during the DPT (see Figure 5C,D), the ANOVA showed a significant main effect of Emotion compatibility ($F_{1,40} = 9.503$, $p = 0.004$, $\eta_p^2 = 0.192$), indicating faster RTs for compatible than incompatible trials. The main effect of Spatial compatibility was significant as well ($F_{1,40} = 4.732$, $p = 0.036$, $\eta_p^2 = 0.106$), with faster RTs for compatible than incompatible trials. Moreover, the interaction between Emotion and Spatial compatibility was significant ($F_{1,40} = 5.110$, $p = 0.029$, $\eta_p^2 = 0.113$). Post-hoc tests showed that the RTs were faster when the target appeared on the same side as the side occupied by the fearful

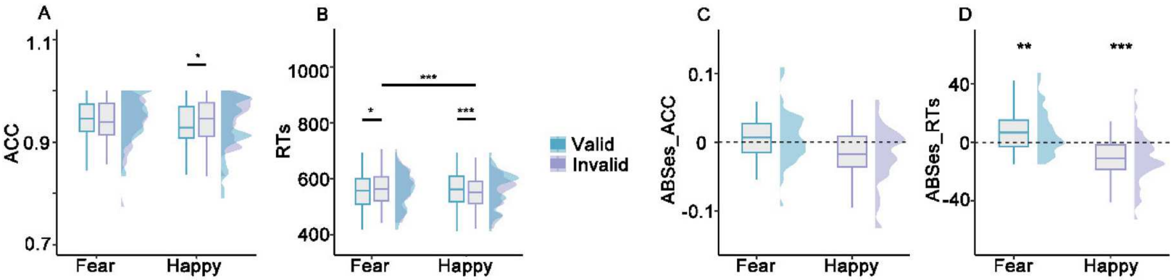

Figure 4. Results for the DPT in Experiment 2. In each graph, the mean performance is shown in a boxplot along with their distribution (half-density with colour).

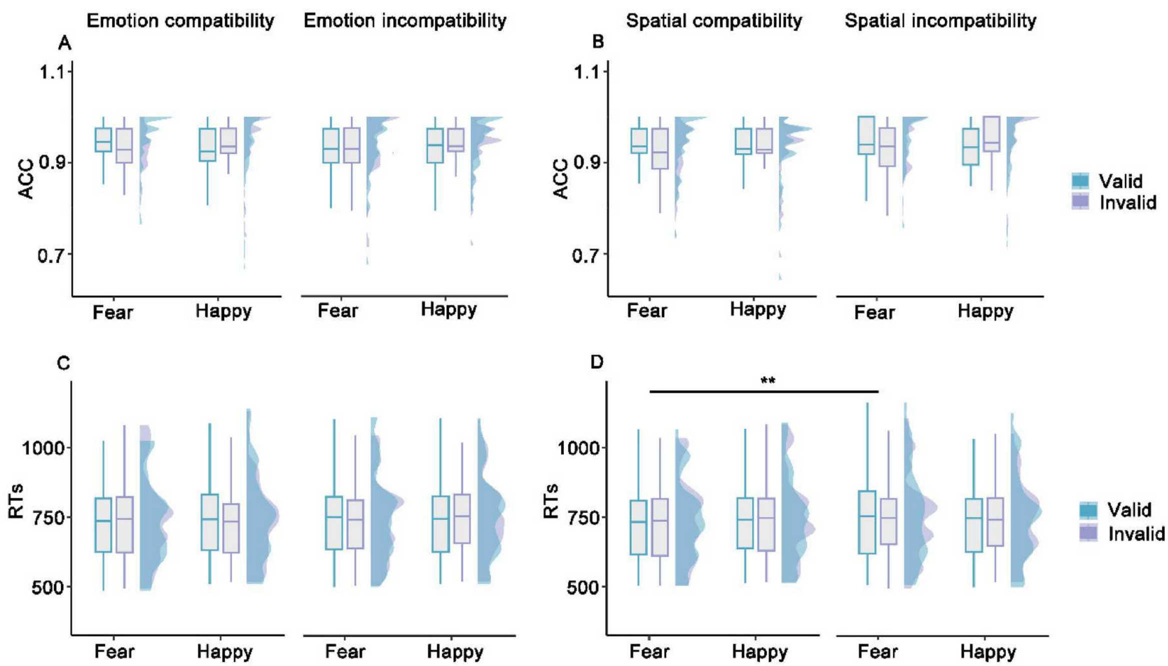

Figure 5. ACC (top row) and RTs results (bottom row) for the DPT in Experiment 3. (A&C) Effect of Emotion compatibility on ACC (A) and RTs (C). Effect of Spatial compatibility on ACC (B) and RTs (D). In each graph, the mean performance is shown in a boxplot along with their distribution (half-density with colour).

face in the (immediately) preceding induction trial (t_{40} = −3.137, p = 0.014, Cohen's d = −0.102). Although the three-way interaction between Emotion, Validity, and Emotion compatibility was significant ($F_{1,40}$ = 4.631, p = 0.037, η_p^2 = 0.104), none of the post-hoc tests reached significance. The Bayesian ANOVA provided moderate evidence in favour of including the main effect of Emotional compatibility (BF_{incl} = 3.196), anecdotal evidence for including the main effect of Spatial compatibility (BF_{incl} = 1.041), and anecdotal evidence for including the interaction between Emotion and Spatial compatibility (BF_{incl} = 1.671).

Combined results

First, we compared performance for induction trials between Experiment 2 and 3. For ACC (see Figure 3A,B), the ANOVA showed a significant main effect of Experiment ($F_{1,79}$ = 46.890, p < 0.001, η_p^2 = 0.372; BF_{incl} = 5.214*10^{+6} suggesting decisive evidence), with a higher ACC for Experiment 3 than 2. The main effect of Emotion was significant as well ($F_{1,79}$ = 8.106, p = 0.006, η_p^2 = 0.093; BF_{incl} = 5.807 suggesting moderate evidence), indicating a higher ACC for happy-neutral face pairs compared to fearful-neutral face pairs. The interaction effect between Emotion and Experiment was not significant ($F_{1,79} = 1.832$, $p = 0.180$). For the RTs (see Figure 3C,D), the main effect of Experiment was significant ($F_{1,79} = 88.928$, $p < 0.001$, $\eta_p^2 = 0.530$; $BF_{\text{incl}} = 1.382*10^{+11}$ suggesting decisive evidence), indicating faster RTs for Experiment 3 than 2. The main effect of Emotion was also significant ($F_{1,79} = 20.253$, $p < 0.001$, $\eta_p^2 = 0.204$; $BF_{\text{incl}} = 578.231$ suggesting decisive evidence), indicating faster RTs for happy-neutral face pairs than fearful-neutral face pairs. The interaction between Emotion and Experiment was marginally significant ($F_{1,79} = 3.369$, $p = 0.070$, $\eta_p^2 = 0.041$).

Next and importantly, we directly compared behavioural performance for the DPT between the three experiments. For the RTs, the main effect of Experiment was significant ($F_{2,\ 118} = 80.297$, $p < 0.001$, $\eta_p^2 = 0.576$; $BF_{\text{incl}} = 7.567*10^{+18}$ suggesting decisive evidence for including this effect). RTs were faster in Experiment 1 than 3 ($t_{118} = -12.396$, $p < 0.001$, Cohen's $d = -2.736$) and 2 ($t_{118} = -3.959$, $p < 0.001$, Cohen's $d = -0.879$). RTs were also faster for Experiment 2 than 3 ($t_{118} = -8.412$, $p < 0.001$, Cohen's $d = -1.857$). The interaction between Emotion and Validity was significant ($F_{2,\ 118} = 21.054$, $p < 0.001$, $\eta_p^2 = 0.151$; $BF_{\text{incl}} = 2593.219$ suggesting decisive evidence for including this effect). Post-hoc tests showed that RTs were faster for happy invalid than either happy valid ($t_{118} = -4.094$, $p < 0.001$, Cohen's $d = -0.069$) or fear invalid trials ($t_{118} = -3.992$, $p < 0.001$, Cohen's $d = -0.068$). Moreover, the three-way interaction of Emotion, Validity and Experiment was also significant ($F_{2,\ 118} = 6.542$, $p = 0.002$, $\eta_p^2 = 0.100$; $BF_{\text{incl}} = 26.727$ suggesting strong evidence for including this effect). A closer look at this three-way interaction suggested that the two-way interaction between Emotion and Validity was stronger either in Experiment 1 ($F_{1,79} = 9.258$, $p = 0.003$, $\eta_p^2 = 0.105$; $BF_{\text{incl}} = 18.541$ suggesting strong evidence for including this effect) or in Experiment 2 ($F_{1,79} = 5.574$, $p = 0.021$, $\eta_p^2 = 0.066$; $BF_{\text{incl}} = 3.978$ suggesting moderate evidence for including this effect) than in Experiment 3, while it was comparable for Experiments 1 and 2 ($F_{1,78} = 1.781$, $p = 0.186$). For the ABSes computed using RTs, the main effect of Emotion was significant ($F_{1,\ 118} = 21.054$, $p < 0.001$, $\eta_p^2 = 0.125$; $BF_{\text{incl}} = 1657.435$ suggesting decisive evidence for including this effect). Moreover, the interaction between Emotion and Experiment was significant ($F_{2,\ 118} = 6.542$, $p = 0.002$, $\eta_p^2 = 0.100$; $BF_{\text{incl}} = 26.320$ suggesting strong evidence for including this effect). Happy was marginally stronger in Experiment 2 than in 3 ($t_{118} = -2.757$, $p = 0.069$, Cohen's $d = -0.613$). The main effect of Experiment was non-significant ($F_{2,\ 118} = 0.381$, $p = 0.684$).

Discussion

When considering RTs, which are the main dependent variable under consideration in this study, the results of Experiments 1 and 2 converge and clearly lend support to the automaticity view according to which fearful faces captured attention automatically in this DPT (Fox, 2002; Lipp & Derakshan, 2005; Mogg & Bradley, 1999; Pourtois et al., 2004). Indeed, this capture was not stronger (or weaker) in Experiment 2 where induction trials where used than Experiment 1, but comparable for them, and the corresponding Bayes factor ($BF_{\text{incl}} = 0.512$) indicated moderate evidence for it. Specifically, participants discriminated the shape of the target faster when it was preceded by a fearful face compared to a neutral face in the pair serving as a cue. Because we used a short and variable interval between cue and target, and the emotional face was never predictive of target location (Egeth & Yantis, 1997), this result unambiguously suggests that a rapid and automatic orienting of spatial attention towards the location occupied by the fearful face in the pair took place during this DPT (Phelps et al., 2006; Pourtois et al., 2004). Moreover, because we used eye-tracking and removed offline trials contaminated by eye movements towards either the (emotional) face or the target (see Table S1, supplementary materials), these results confirm that this effect truly corresponded to a covert shift of spatial attention (Corbetta et al., 1998; Egeth & Yantis, 1997). Remarkably, our new results clearly suggest that this attentional bias towards fearful faces was not restricted to fear, but it extended to negative valence (when conceived as a dimension, see Russell, 1980). Not only were participants faster for fear valid than fear invalid trials, but they were also symmetrically faster for happy invalid than happy valid trials, and this effect was very strong ($BF_{10} = 1.881 * 10^{+6}$). The latter effect suggests that when a neutral face competed for attention selection with a happy face, the former captured attention, and this capture was likely automatic as well because induction trials (in Experiment 2) did not modulate it. Previous research (Adolphs, 2002; Calvo & Nummenmaa, 2008; Lee et al., 2008) already showed that neutral faces, especially when they are shown briefly, can be confused with negative stimuli. The results for the induction trials in Experiment 3 also support this interpretation. Hence, these findings suggest that negative emotion captured attention (Vuilleumier, 2005), and this capture was seemingly automatic because it was observed when emotion was not task-relevant (Experiment 1), while it was not stronger when it was so (Experiment 2). As such, these results also align well with previous studies based on the DPT that already reported an automatic capture of attention by negative emotion (Dolan & Vuilleumier, 2003; Lipp & Derakshan, 2005; Pourtois et al., 2004; Sutton & Altarriba, 2011).

However and importantly, this bias largely disappeared in Experiment 3 where the contingency between the induction trials and dot-probe trials was full (see Figure 6). Therefore, this result suggests that the capture of attention by negative emotion was not automatic and it aligns with a handful of previous studies that already showed that goal relevance could effectively modulate emotional attention (Brown et al., 2020; Qiu et al., 2023; Vogt et al., 2013; Vromen et al., 2016). A potential explanation for the absence of attentional bias in Experiment 3 is that the goal relevance of emotion was high, in turn altering and reducing the weight of emotional value on attentional control during the DPT (Everaert et al., 2013). Moreover, according to the priority map's notion, goal, value, and salience can each contribute to attention selection (Awh et al., 2012; Bisley & Mirpour, 2019; Pourtois et al., 2013). However, depending on the current task demands, their respective weight can vary (Cunningham et al., 2021; Stein et al., 2009). In Experiment 3, the weight of goal was heavier than the one assigned to value. As a result, attention selection was mostly guided or assisted by goal at the expense of value. Alternatively, the limited availability of working memory resources for value could explain the results of Experiment 3 (Van Dillen & Hofmann, 2023). Previous studies have shown that selective attention to negative affective stimuli is reduced when working memory load increases, such as achieved by performing a cognitively demanding task (Carter et al., 2003; Van Dillen & Derks, 2012; Van Dillen & Koole, 2007). In our study, working memory load was low in Experiment 1 (no induction trials). It increased in Experiment 2 (where induction trials were deviant) but it was taxed the most in Experiment 3 (where induction trials were dominant).

Intriguingly, despite the absence of an attentional bias towards negative emotion in Experiment 3, fearful faces produced a distinct effect on spatial attention in that experiment because when shown at a specific location during the induction trials, they facilitated target processing at the exact same location during the subsequent dot probe trial (cf. interaction between Emotion and Spatial compatibility), thereby indicating a prolonged attentional capture by fear. This effect was not found with happy faces, suggesting that it was confined to fear. Because a long interval occurred between the emotional face of the induction trial and the subsequent target of the DPT (minimum of 2000 ms), one could imagine that fear had perhaps an effect on Inhibition of Return (IOR; see also Fox et al., 2001). According to the IOR principles (Klein, 2000; Posner et al., 1985; Posner & Cohen, 1984), responses tend to be faster for cued compared to uncued targets when the stimulus-onset asynchrony (SOA) is short. However, when increasing the SOA, this effect reverses, resulting in slower responses to cued than uncued targets. The crossover point is usually between 200 and 300 ms. Translated to our findings, we should therefore observe slower RTs for compatible than incompatible fear trials, which we did not

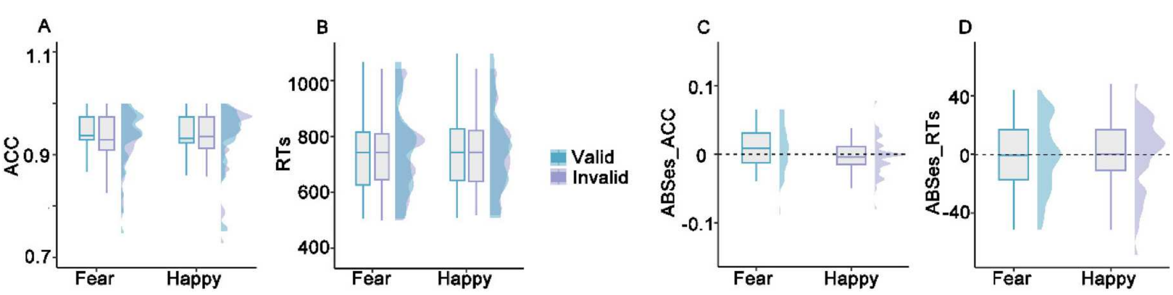

Figure 6. Results for the DPT in Experiment 3 when only Emotion and Validity were considered (in analogy with Experiments 1 and 2). In each graph, the mean performance is shown in a boxplot along with their distribution (half-density with colour).

report, however. Instead, we found that despite the long interval used between the fearful face of the induction trial and the subsequent target of the DPT, participants were faster for compatible than incompatible trials, suggesting capture rather than disengagement driven by fear (Fox et al., 2002; Koster et al., 2004). Because this effect did not interact with Validity (i.e. actual position of the emotional face at the cue level during the DPT), one may speculate that the participants of Experiment 3 could merely ignore this emotional face and hence the cue. In this scenario, goal relevance would create a strong bias whereby emotional processing would mostly concern the induction trials but not the dot probe trials (Everaert et al., 2013). However, we also found that the main effect of Emotional compatibility was significant, suggesting that participants did process the emotional face at the cue level, and this, equally strongly for fear and happiness. This effect shows that they were faster to process the target when the emotional face used at the cue level had the same valence as the one used in the preceding induction trial, yet irrespective of their respective spatial locations, hence sharing similarities with an evaluative priming effect (Aguado et al., 2013; De Houwer et al., 2002; Hart et al., 2010). This emotional compatibility effect also indirectly suggests that induction trials eventually produced the expected effect, namely a top-down attentional control bias towards emotion (both fear and happiness). In Experiment 3, emotion therefore had a high goal status and as such, it was probably prioritised by the participants, yet it did not produce an attentional bias. Tentatively, we can assume that given this goal prioritisation, the spatial processing of the target was no longer driven by the preceding emotion (cue) because, during this event, no emotion was shown. Hence, for the target, its processing was not influenced by the position of the fearful or happy face shown at the cue level, as was found in Experiments 1 and 2. Additional studies are needed to elucidate this non-spatial emotional compatibility effect found for fear because paradoxically at firt sight, it might even be responsible for the reduction of the attentional bias for negative emotion found during the DPT in Experiment 3.

Another worth-mentioning finding pertains to the performance of the induction trials when comparing Experiments 2–3. Participants were faster at discriminating the side where the emotional face was shown in the latter experiment. This result suggests that goal relevance of emotion was probably weak or suboptimal in Experiment 2, which might explain why it did not influence emotional attention and yielded similar results as Experiment 1. The results for the induction trials also corroborate this conclusion. Hence, our results underscore the crucial role of goal's contingency in modulating attentional processes (Barratt & Bundesen, 2012; Schmidt, 2014; Schmidt & Besner, 2008) and more generally, they suggest that the capture of attention by threat-related stimuli is probably flexible in the sense of depending on goal relevance's strength (Moors & De Houwer, 2006). Instead of a binary distinction between automatic and non-automatic processes (Broadbent, 1958; Deutsch et al., 1963), the capture of attention by negative emotion seems to be variable and as such, it could manifest along a continuum (Hasher & Zacks, 1979; Shiffrin & Schneider, 1977; Zbrodoff & Logan, 1986). If emotion is not goal-relevant (Experiment 1) or associated with a weak goal presumably (Experiment 2), then the processing of negative emotion is prioritised because it informs participants about possible threats or dangers in the (proximal) environment. However, if emotion is an integral part of the goal (Experiment 3) then this prioritisation is strongly attenuated and a different attentional control set (or perhaps motivational drive, see Inzlicht et al., 2015) is likely at stake. However, in this situation, it is noteworthy that fearful faces could still influence attentional control as if this emotional category could partly resist the strong modulation imposed by goals. Accordingly, fear appears to have a distinct (emotional) value (compared to happiness; see also (Adolphs, 2013)) and when goal is the main attentional control component, this emotion can still influence the priority map (Awh et al., 2012).

Our findings also have clinical implications. Because anxiety and depression are associated with enhanced attention to threat (Beard, 2011; Hakamata et al., 2010; MacLeod & Mathews, 2012) and our results (Experiment 3) show that negative emotion ceased to capture attention when emotion is goal-relevant, it might be valuable to assess in future cognitive bias modification (CBM) or attention bias modification (ABM) studies (Williams et al., 1997) whether patients with internalising psychopathology could benefit from training sessions where induction trials would be used to create a bias away from fear or negative emotion during attentional control.

Limitations and future directions

A few limitations warrant comment. First, given the length (and duration) of the experiment and trial number, it was not possible to use a full within-subject design suited to assess for the same subjects a possible modulation of the capture of attention by threat as a function of goal relevance. Hence, it remains to be shown whether similar results could be found when goal relevance (of emotion) is manipulated in different conditions or blocks for the exact same subjects. Although we sampled participants for these three experiments from the same student population (and the STAI scores were comparable for them), we cannot rule out the possibility that some uncontrolled effects or group differences might have contributed to the main outcome of this study. However, we believe that this alternative interpretation is highly unlikely.

Second, in our study, central fixation was enforced and eye-tracking allowed us to establish that covert shifts of spatial attention actually took place to carry out this DPT. In comparison, in previous studies that found a modulation of emotional attention by goal relevance, these methodological requirements were not met, and hence the use of covert attention to process the emotional cue and the (subsequent) target could not be ascertained. Accordingly, it is conceivable that the effects of goal relevance on emotional attention might be reduced or different when fixation is anchored in the visual field at a fixed position, and covert shifts of spatial attention (driven by negative emotion) have to occur. To address this question, future studies are needed where overt vs. covert shifts of spatial attention towards threat-related stimuli could be compared to each other.

Another limitation of our study is the trial number, which ranged from 640 to 800, which is deemed high and might induce fatigue or boredom, as well as increase habituation. To prevent fatigue, we split the experiment into 8 blocks (each lasting no longer than 5 min) with self-paced breaks introduced between them. Yet, fatigue might have played a role, especially in Experiment 3 and hence influenced emotional attention. To prevent habituation, we created and used a large number of face pairs. Moreover, we made sure (in Experiments 2&3) that there was no immediate repetition of the same face pair for the induction trial and the subsequent dot probe trial. Notwithstanding these precautions, habituation might have contributed to these differential emotional attention effects found in Experiments 1–3.

Last, we believe it would be extremely valuable to use electro-encephalography (EEG) in the future to explore and better characterise the electrophysiological correlates of this attentional capture effect by threat and its modulation by goal relevance (Pourtois et al., 2005). In this context, specific cue-locked or target-locked EEG components might inform about the modulation of spatial attention by goal relevance, besides negative emotion.

Conclusions

In sum, the results of this study show that emotional attention, defined as the prioritisation of negative stimuli during attention selection, depends on the goal relevance of emotion, and as such they can be interpreted using the notion of a priority map. In this framework, fear, unlike happiness, appears to possess a special status however because it can influence attentional control even though the goal promotes the processing of both positive and negative emotion categories.

Transparency and openness

We report how we determined our sample size, all data exclusions, all manipulations and all measures in the study, and the study follows JARS (Appelbaum et al., 2018). All data, analysis code and research materials are available on the Open Science Framework (https://osf.io/5v7tj/). Data were analysed using Matlab R2023a (The Mathworks Inc., Natick, MA, USA) and JASP (version 0.17). Data visualisation was carried out in R Studio (3.3.0), using the ggplot2 package. This study's design and its analysis were not pre-registered.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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