Visual Cognition

ISSN: 1350-6285 (Print) 1464-0716 (Online) Journal homepage: www.tandfonline.com/journals/pvis20

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To cite this article: Stefanie I. Becker, Neelam Dutt, Joyce M. G. Vromen & Gernot Horstmann (2017) The capture of attention and gaze in the search for emotional photographic faces, Visual Cognition, 25:1-3, 241-261, DOI: 10.1080/13506285.2017.1333182

To link to this article: https://doi.org/10.1080/13506285.2017.1333182

Published online: 16 Jun 2017.

VISUAL COGNITION, 2017
VOL. 25, NOS. 1–3, 241–261
https://doi.org/10.1080/13506285.2017.1333182

The capture of attention and gaze in the search for emotional photographic faces

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ABSTRACT

Can emotional expressions automatically attract attention in virtue of their affective content? Previous studies mostly used emotional faces (e.g., angry or happy faces) in visual search tasks to assess whether affective contents can automatically attract attention. However, the evidence in support of affective attentional capture is still contentious, as the studies either: (1) did not render affective contents irrelevant to the task, (2) used affective stimuli that were perceptually similar to the target, (3) did not rule out factors occurring later in the visual search process (e.g., disengagement of attention), or (4) used only schematic emotional faces that do not clearly convey affective contents. The present study remedied these shortcomings by measuring the eye movements of observers while they searched for emotional photographic faces. To examine whether irrelevant emotional faces are selected because of their perceptual similarity to the target (top-down), or because of their emotional expressions, we also assessed the perceptual similarity between the emotional distractors and the target. The results show that happy and angry faces can indeed automatically attract attention and the gaze. Perceptual similarity modulated the effect only weakly, indicating that capture was mainly due to bottom-up, stimulus-driven processes. However, post-selectional processes of disengaging attention from the emotional expressions contributed strongly to the overall disruptive effects of emotional expressions. Taken together, these results support a stimulus-driven account of attentional capture by emotional faces, and highlight the need to use measures that can distinguish between early and late processes in visual search.

ARTICLE HISTORY
Received 22 December 2016
Accepted 15 May 2017

KEYWORDS
Visual search; emotional faces; top-down vs. bottom-up; irrelevant distractor; target similarity

Facial expressions can convey valuable information about a person's intentions and feelings. Thus, for an individual's survival and well-being, it is important to attend to facial expressions and to interpret them correctly with regards to their emotional contents. Given the importance of facial emotional expressions for this task, some researchers have proposed that emotional expressions such as angry, fearful and happy faces are detected automatically and can attract attention independently of a person's goals and intentions. For instance, according to the *threat capture hypothesis*, evolution has equipped us with a threat detector that automatically detects potentially threatening stimuli in the environment and directs attention to corresponding stimuli (e.g., Juth, Lundqvist, Karlsson, & Öhman, 2005; Öhman & Mineka, 2001; Öhman, Lundqvist, & Esteves, 2001). Additionally, or alternatively, it has been proposed that humans are equipped with detectors for friendly faces, as these can signal possible allies and positive human affordances such as possible sources for food and shelter (*ally detector*; Becker, Anderson, Mortensen, Neufeld, & Neel, 2011).

The hypothesis that emotional expressions can attract visual attention in virtue of their emotional contents (hereafter, *affective capture hypothesis*) is to a large extent based on visual search studies that show that angry faces can be detected faster than happy faces when the emotional face is presented among neutral non-target faces or among faces with the opposite expression (e.g., Eastwood, Smilek, & Merikle, 2001; Fox, Russo, Bowles, & Dutton, 2001; Horstmann, 2007; Horstmann & Bauland, 2006; Juth et al., 2005; Lipp, Price, & Tellegen, 2009; Öhman et al., 2001; Pinkham, Griffin, Baron, Gur, & Sasson, 2010). However, the finding that one target stimulus can be found faster than another stimulus cannot establish that attention was automatically attracted to the stimulus in virtue of its emotional content. As detailed by Horstmann and Becker (2008), there are at least three major problems with this inference.

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First, it is well-known that stimuli can attract attention in virtue of their *perceptual attributes*. In fact, the major theories of visual search (e.g., Duncan & Humphreys, 1989; Treisman & Sato, 1990; Wolfe, 1994) all rely on perceptual attributes to explain search performance and, in face search, salient attributes such as visible teeth strongly modulate attention (e.g., Horstmann, Lipp, & Becker, 2012). Hence, we can only safely conclude that attention was modulated by the emotional contents of facial expressions if we have ensured that the effects cannot be attributed to confounding perceptual factors (which is very difficult; for an overview see Becker, Anderson, et al., 2011; Frischen, Eastwood, & Smilek, 2008). Second, the affective capture hypothesis entails that attention was automatically and involuntary drawn to the emotional face. This is difficult to establish when the task requires searching for an emotional face (i.e., when the emotional face is the target), because the observed effects could alternatively be due to top-down search strategies. It is well-known that attention can be actively tuned or biased to specific features of the target, and that this top-down setting or search template can then guide visual attention to corresponding stimuli in the environment (e.g., Duncan & Humphreys, 1989; Folk, Remington, & Johnston, 1992; Wolfe, 1994). A third, related, problem is that differences in search performance cannot always be safely attributed to the target. As shown in the seminal paper by Duncan and Humphreys (1989), search performance is strongly influenced by the difficulty of distractor rejection. For instance, if the non-targets are all very similar to each other (and dissimilar from the target), they can be grouped together and rejected very efficiently as a "structural unit," which can render search very efficient. Such grouping processes have also been shown to modulate the search for emotional faces, at least with schematic faces (Becker, Horstmann, & Remington, 2011). Hence, faster search for emotional faces cannot be safely attributed to the target, as it could also be due to more efficient grouping and rejection of the non-target items (see also Horstmann, Herwig, & Becker, 2016; Horstmann, Becker, & Ernst, in revision).

To prevent these complications and safeguard the conclusion that the emotional face automatically attracted attention, it is necessary to render the emotional face completely irrelevant to the task, such that it is unrelated to the target-defining attribute and the reported attribute (e.g., Becker, 2007; Folk & Remington, 1998; Folk et al., 1992; Yantis, 1998). For instance, to establish that angry faces can automatically attract attention, it would be necessary to define the search target by a different facial feature (e.g., gender), and to present the angry expression equally often at the location of each irrelevant non-target and the target, so that the angry face does not predict the target.

Most studies that examined the effects of emotional stimuli on attention did not render emotional faces irrelevant to the task, and therefore cannot address the question of whether emotional expressions can automatically attract attention. Among the few notable exceptions are studies by Huang, Chang, and Chen (2011), Hunt, Cooper, Hungr, and Kingstone (2007), and Horstmann and Becker (2008), which examined effects of irrelevant emotional schematic faces when the target was defined by a different feature (e.g., black superimposed dot). Hunt et al. (2007) found no evidence for attentional capture by emotional schematic faces (see also Barratt and Bundesen, 2012, for similar results in a flanker task). Huang et al. (2011) found that only angry faces automatically attracted attention, whereas happy faces exerted only weak effects on attention. Horstmann and Becker (2008) found only very weak evidence for an attentional bias, also to negative faces.

However, these studies can still be criticized for their use of schematic stimuli. Schematic faces are of low ecological validity and therefore may not provide a fair test of the affective hypothesis, as they may not trigger a threat detector or ally detector. Correspondingly, there is now ample evidence that effects of schematic faces can be largely due to perceptual factors and independent of their emotional contents (e.g., Becker, Horstmann, et al., 2011; Coelho, Cloete, & Wallis, 2010; Horstmann, Becker, Bergmann, & Burghaus, 2010).

There is only one study that assessed the effects of photographic emotional faces when these were irrelevant and participants had to search for a gender target (i.e., male target among two female non-target faces; Hodsoll, Viding, & Lavie, 2011). In this search task, angry, fearful and happy non-target faces all significantly interfered with search. However, when the emotional face was presented at the location of the target, only happy faces were found faster than a neutral face, whereas there was no facilitation for either angry or fearful faces. This result contrasts with previous findings, which mostly found stronger effects for angry and fearful faces rather than happy faces (e.g., Horstmann & Becker, 2008; Huang et al., 2011). Although the results of Hodsoll et al. (2011) support an ally detector over a threat detector, they maintained that all emotional faces had automatically attracted attention and reasoned that the absence of facilitation effects for angry and fearful targets could be due to an additional cost associated with "processing negative emotions and its unpleasant connotations" (p. 352).

Alternatively, the absence of a significant facilitation effect indicates that the emotional expressions may not have captured attention but that they may have been suppressed or "filtered out" in a time-consuming process (e.g., Folk & Remington, 1998). Additionally or alternatively, the finding of interference without facilitation could be due to the fact that emotional faces simply hold attention for longer once they are selected. Several studies have shown evidence that emotional faces can interfere with such post-selectional processes, as more time is needed to disengage attention from emotional faces, especially angry faces (e.g., Belopolsky, Devue, & Theeuwes, 2011; Fox et al., 2001). In the absence of a significant facilitation effect, attentional capture cannot be distinguished from filtering costs or later costs of disengaging attention, so that it is still unclear whether emotional faces can really attract attention.

Another aspect that seems worth mentioning is that previously observed effects could have been due to the perceptual similarity of emotional faces, not their affective content. According to current theories of visual search, attention will usually be tuned or biased to the attributes of the search target (e.g., Duncan & Humphreys, 1989; Wolfe, 1994), so that the attention-driving capacity of a stimulus depends critically on whether it matches or mismatches these attributes. As shown by Folk and colleagues (Folk & Remington, 1998; Folk et al., 1992), stimuli that are similar to the target can reflexively attract attention even when they are completely irrelevant to the task (see also Becker, Ansorge, & Horstmann, 2009). Subsequent studies have moreover shown that these *similarity effects* can also modulate visual search for emotional faces (Horstmann et al., 2012, 2016).

Perceptual similarity (Duncan & Humphreys, 1989) can also potentially explain a subset of previous findings with emotional distractor faces. An angry distractor face may be more perceptually similar to a male target face because angry female faces appear more masculine (e.g., Hess, Adams, Grammer, & Kleck, 2009). Thus, if angry female distractors are indeed more similar to a male target face, it is possible that stronger capture effects of angry faces were due to the fact that these distractors were more confusable with the male target.

A final point worth mentioning is that the emotional distractors in the study of Hodsoll et al. (2011) were not entirely non-predictive of the target. In fact, emotional expressions were present on 33% of the trials and presented equiprobably at the target location or a distractor location. As the search displays always contained three items, emotional expressions (when present) indicated the target location with above-chance probability (chance: 33%). Previous studies have shown that irrelevant salient features (e.g., different colours) are attended more the more frequently they coincide with the target (e.g., Yantis & Egeth, 1999; see also Geyer, Müller, & Krummenacher, 2008). With respect to affective faces, it is not clear whether small deviations from chance probability would have the same effect. Thus, to ascertain automatic attentional capture by emotional faces, it would be necessary to render emotional distractors completely non-predictive of the target.

In sum, previous studies have provided some evidence for the *affective capture* hypotheses, that emotional faces are preferentially attended. However, the current evidence does not allow any definite conclusions about a threat vs. ally detector. Moreover, the evidence for either hypothesis is still quite weak, as previous studies did not use the appropriate methods or measures to safeguard their results against alternative explanations, which could, for instance, involve top-down guidance (rather than capture), post-selectional processes (e.g., disengagement), filtering of distractors, or perceptual factors.

Aim of the present study

The aim of the present study was to provide a more decisive test of the affective capture hypothesis. To that aim, the current study tested whether emotional photographic faces can indeed automatically attract attention when the potential pitfalls listed above are avoided. The visual search task was closely modelled onto the study of Hodsoll et al. (2011). Across two experiments, we rendered the emotional distractor either entirely non-predictive of the target (Experiment 2), or used the same probabilities as used in Hodsoll et al. (Experiment 1; 50% valid), to assess whether capture by emotional expressions would vary with the predictiveness of the distractor, and assess the possible contributions of top-down vs. bottom-up processes to capture. In advance to Hodsoll et al. (2011), we also monitored the observers' eye movements during search, to distinguish attentional capture from later disengagement processes (e.g., Becker, 2008; Deubel & Schneider, 1996) and distractor filtering (e.g., Folk & Remington, 1998). Moreover, we tested whether (stronger) capture by angry faces may have been due to the distractors being perceptually similar to the target, by obtaining masculinity ratings for all emotional faces after the visual search task, and reversing the role of target and distractor in Experiment 2. Specifically, we compared distraction by an emotional face in search for a male face to distraction by a male face in search for an emotional face (in physically identical displays). This allows gauging whether the effects of emotional distractors are solely due to the perceptual similarity of emotional faces with male faces.

Experiment 1

In Experiment 1, we used the visual search task of Hodsoll et al. (2011) to assess the effects of happy and angry emotional faces. Participants had to make a fast and precise eye movement to a male target that was embedded among all-female faces, while ignoring the emotional expressions of the faces. The male and female faces had all neutral expressions, except on distractor present trials (33.3%), in which either the target or a non-target showed an angry or happy face (blocked; 50% emotional target face). Once participants had located the target, they had to report the tilt of the target face with a button press (right/left tilted target face).

To assess attentional capture by the emotional faces, we measured the proportion of first eye movements to the distractor as an index of whether the distractor elicited a fast eye movement to its location (e.g., Becker, 2008; Theeuwes, deVries, & Godijn, 2003; Theeuwes, Kramer, Hahn, & Irwin, 1998). To assess possible contributions of later disengagement processes to the interference effect, we also measured the dwell times on the distractor (on invalid trials; e.g., Becker, 2008; Belopolsky et al., 2011).

As in previous studies, facilitation was assessed by comparing target singleton trials (in which the target had the emotional expression) to the all-neutral trials, which did not contain any emotional faces (difference score: all-neutral condition – emotional target). Interference was defined as a performance impairment when the emotional face was presented at the location of an irrelevant distractor compared to the all-neutral condition (difference score: emotional distractor – all-neutral condition). In advance to previous studies, eye tracking allowed assessing whether facilitation and interference effects occurred at an early or late stage of visual processing.

According to Hodsoll et al. (2011), processing of negative affect is more time-consuming and thus neutralizes an early facilitation effects for angry faces during a later stage of processing. If this is correct, facilitation and interference effects should both modulate search at an early stage and should therefore be reflected in the mean search times, that is, the time needed to select the target (i.e., time from the onset of the search display to point in time when the gaze first selected the target). However, the facilitation effect should then be reduced or eliminated in the mean RT (at least for the angry face) if processing of negative affect is indeed more time-consuming.

An alternative explanation for the frequent failure to observe capture and, especially, facilitation effects for emotional faces could be rooted in the sparse stimulus displays used in previous studies (e.g., set size 3 in Hodsoll et al., 2011). Specifically, using only 3-item displays may have rendered the paradigm quite insensitive to facilitation, because the a priori probability of selecting the target or distractor as the first item is already quite high (33.3%). To assess this possibility, we used a set size 6 condition in addition to the set size 3 condition used in Hodsoll et al. (2011). The two set size conditions (3, 6) and the two emotional distractor conditions (angry, happy distractor) were blocked, to avoid that participants would bias attention more strongly to a particular display layout or a variable distractor feature (e.g., angry or happy faces; Becker, Horstmann, et al., 2011).

Methods

Participants

Eighteen observers with normal or corrected-to-normal vision participated in Experiment 1. One participant had to be excluded due to failing to look at the target on more than 20% of trials. The 17 remaining participants consisted of 10 males and 7 females ($M_{age} = 22$ years, $SD = 8.52$, age range: 17–46 years). All participants were naïve as to the purpose of the experiment.

Apparatus

An Intel Duo 2 CPU 2.4 GHz computer with a 17-inch LCD colour monitor was used to generate and display the stimuli. Stimuli were presented at a resolution of 1280 × 1024 pixels and a refresh rate of 75 Hz. A video-based infrared eye-tracking system was used (Eyelink 1000, SR Research, Ontario, Canada) with a spatial resolution of 0.1° of visual angle and temporal resolution of 500 Hz. The left and right buttons of a standard mouse were used as left and right response buttons, respectively.

Stimuli

Stimuli consisted of 48 grey-scale photographic images of faces with different emotional expressions from the NimStim face stimulus set (Tottenham et al., 2009). These included eight male and female models (Models 1, 2, 3, 5, 6, 7, 8, 9, 20, 22, 23, 24, 33, 34, 36, 37), in poses HA_O (happy open mouth), AN_O (angry open mouth), and NE_C (neutral closed mouth). The photographic images were rendered in grey scale prior to testing. The mean brightness of the images (as computed by the Image.Stat function of the Python's PIL library) was very similar for angry, happy, and neutral faces (mean RGBs: angry faces = 123; happy faces = 120; neutral faces = 122; $F(2,14) = 2.1$, $p = .16$). On average, the male faces were slightly darker ($M = 117$) than the female faces ($M = 126$); however, the range of different brightness values across the different faces ensured that brightness could not be used to find the target or filter out the distractor (ranges: angry female: 117–135 ($M = 129$); angry male: 104–134 ($M = 118$); happy female: 112–135 ($M = 124$); happy male: 100–140 ($M = 117$); neutral female: 114–134 ($M = 128$); neutral male: 101–142 ($M = 117$)). The faces were enclosed within an upright oval (4.8° of visual angle high × 3.4° of visual angle wide) so that only the faces were visible (see Figure 1). The search display consisted of a male target face and two or five female faces from different models. All stimuli were presented equidistantly on the outlines of an imaginary circle (radius: 9.2°). In the set size 6 condition stimuli were presented at the 1, 3, 5, 7, 9, and 11 o'clock positions, and in the set size 3 condition stimuli were randomly presented either in the 1, 5, and 9 o'clock positions or in the 3, 7, and 11 o'clock positions (to maintain the same degree of a priori location uncertainty across conditions). All search stimuli were tilted 15 degrees to the left or right.

Design

The experiment consisted of four blocked conditions, in which the irrelevant emotional expression was either an angry or happy face, presented among either three or six stimuli. As in the study of Hodsoll et al. (2011), the male target face was presented among all-neutral female non-target faces on 66.6% of all trials. On half of the remaining 33.3% of trials, an emotional face (angry or happy) was presented equiprobably at the location of the target or a non-target (resulting in a male happy target or female happy distractor). Participants completed 192 trials in each set size × distractor emotion block, while the type of trial (all neutral, emotional target, emotional distractor) varied randomly within each block. The identity of male and female models was drawn randomly on each trial, with the limitation that no face was presented more than once within the same display. The target and distractor positions and the tilt of each face were also chosen randomly with the limitation that half of the faces had to be tilted in either direction (set size 6), or that at least one face was tilted in a different direction (set size 3). Participants completed 768 trials in total, and the first 10 trials in each block were discounted as practice trials.

Procedure

Participants were seated in a normally lit room, with their head fixated by the eye tracker's chin rest and forehead support, and viewed the screen from a distance of 62 cm. Prior to the experiment, participants were calibrated with a 9-point calibration, and instructed about the presence and characteristics of possible distractors. All participants were instructed to make a fast and precise eye movement to the target whilst trying to ignore the distractor, and to

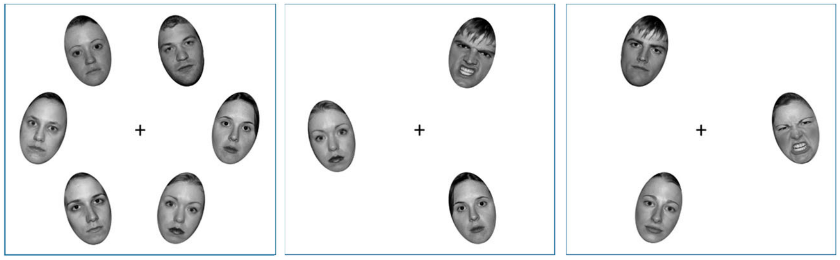

Figure 1. Examples of the conditions used in Experiment 1 and Experiment 2, when observers were searching for the male target and had to ignore any emotional expressions. The leftmost panel depicts an example of an all-neutral trial in the set size 6 condition, the middle panel an emotional target trial (singleton target trial), and the rightmost panel an emotional distractor trial (singleton distractor trial) in the set size 3 conditions.

report whether the male target face was tilted to the right or left by pressing the right or left mouse button.

Each trial started with the presentation of a black central fixation cross. To ensure accurate eye tracking, a fixation control was implemented: The target display was presented only when the gaze was within 50 pixels of the centre of the cross, for at least 700 ms, within a time window of 2000 ms (otherwise participants were calibrated anew). The target display was presented until the manual button press response, and immediately followed by a feedback display containing the written words “correct” or “wrong” (Arial Black, 13pt). To encourage participants to respond accurately and discourage trading speed for accuracy, the correct feedback screen was presented for 750 ms whereas the wrong feedback was presented for 1250 ms, respectively. Both were followed by a 250 ms blank display.

Rating Task (RT)

To collect the ratings of the perceived masculinity of the faces, the happy, angry and neutral female faces used in the visual search task were presented at the centre of the display (all in an upright orientation). Below the images, a 7-point Likert scale was displayed and observers were asked to press one of the number keys 1–6 on the keyboard to indicate whether they perceived the female face to be 1: very masculine, 2: masculine, 3: somewhat masculine, 4: somewhat feminine, 5: feminine, or 6: very feminine.

Results

Data

Eye movements were parsed into saccades, fixations and blinks using the standard parser configuration of the Eyelink software, which classifies an eye movement as a saccade when it exceeds a velocity of 30°/s or an acceleration of 8000°/s^2. Fixations were assigned to a stimulus (target, neutral non-target or distractor face) when the gaze was within 160 pixels of the centre of a stimulus (about half of the distance from the fixation point to the stimulus).

Trials with very short response times (RT; < 300 ms) or long RTs (> 3000 ms) were excluded from all analyses, which accounted for a loss of 0.69% of all data. Moreover, for the analysis of eye movement data, trials without a fixation on the target stimulus were excluded, which led to a further loss of 2.87% of all data. For the analysis of mean RT and the eye movement parameters, all trials with a manual error were excluded (3.5% of the data).

Mean RT

Mean RT were first analysed with a 2 × 2 × 3 ANOVA with the variables emotion (angry, happy), set size (3, 6), and trial type (all-neutral, target emotion trial, distractor emotion trial). The results showed significant main effects of set size, $F(1,16) = 68.3$, $p < .001$, $\eta^2 = .81$, trial type, $F(2,32) = 103.2$, $p < .001$, $\eta^2 = .87$, a significant emotion × trial type interaction, $F(2,32) = 7.1$, $p = .004$, $\eta^2 = .31$, and a significant set size × trial type interaction, $F(2,32) = 34.1$, $p < .001$, $\eta^2 = .68$, whereas the three-way interaction just failed to reach significance, $F(2,32) = 2.9$, $p = .071$.

As shown in Figure 2(A), the predicted results pattern of facilitation for emotional targets and interference for emotional distractors (compared to the all-neutral faces condition) was observed across both emotional expressions (angry, happy) and all set size conditions. Specifically, happy faces showed significant facilitation effects in the set size 3 condition, $t(16) = 2.2$, $p = .040$, and in the set size 6 condition,

$t(16) = 6.2$, $p < .001$, as well as significant interference effects in the set size 3 condition, $t(16) = 3.4$, $p = .003$, and the set size 6 condition, $t(16) = 4.5$, $p < .001$. The angry face similarly showed significant facilitation effects both in the set size 3 condition, $t(16) = 4.3$, $p = .001$, and the set size 6 condition, $t(16) = 10.2$, $p < .001$, and the angry distractor also significantly interfered with search in the set size 3 condition, $t(16) = 9.3$, $p < .001$, and the set size 6 condition, $t(16) = 4.5$, $p < .001$.

Facilitation and interference effects were both larger in the set size 6 than the set size 3 condition. In the set size 6 condition, the mean facilitation by emotional target faces was 157 ms (happy: 151 ms, angry: 164 ms) and the mean interference by emotional distractor faces was 127 ms (happy: 110 ms, angry: 144 ms), whereas in the set size 3 conditions, the mean facilitation was only 44 ms and the interference was 95 ms (happy: 47 ms, angry: 143 ms). The results show that the set size 3 condition is not very sensitive to effects of the distractor placement, and establish that it is especially insensitive to facilitation effects for emotional target trials.

To examine whether angry and happy faces exerted different effects that would point towards a threat or ally detector determining search performance, we also compared the pattern of facilitation and interference between happy and angry faces. The results showed that facilitation and interference effects were of the same magnitude for angry and happy faces in the set size 6 condition. In the set size 3 condition, happy and angry faces facilitated responses to the same extent; however, the angry distractor interfered significantly more with search than the happy distractor, $t(16) = 5.4$, $p < .001$ (all other $ps > .30$).

Search time

To examine whether the results of the mean RT reflected genuine search processes, the same analyses were conducted for the mean search times (i.e., the time from the onset of the search display until the gaze fixated on the target for the first time; see Figure 2(B)). The $2 \times 2 \times 3$ ANOVA computed over the mean search times revealed the same results as found in the mean RT; with significant main effects of set size, $F(1,16) = 128.9$, $p < .001$, $\eta^2 = .89$, trial type, $F(2,32) = 78.1$, $p < .001$, $\eta^2 = .83$, a significant emotion × trial type interaction, $F(2,32) = 6.6$, $p = .005$, $\eta^2 = .29$, and a significant set size × trial type interaction, $F(2,32) = 22.5$, $p < .001$, $\eta^2 = .58$, but no significant interaction between all three variables, $F < 1$.

The mean search times also showed the expected pattern of faster search for emotional targets and slowed search in the presence of an emotional distractor, with the sole exception of the happy target face in the set size 3 condition, which failed to produce significant facilitation compared to the neutral condition; all other $ts > 2.5$, $ps < .030$ (see Figure 2(B)).

Comparing the magnitude of facilitation and interference across the conditions revealed that the set size 6 condition again showed far larger facilitation effects (of 125 ms) for emotional targets (happy: 112 ms, angry: 137 ms) than the set size 3 condition, which showed only a benefit of 28 ms (happy: 14 ms, angry: 42 ms), $t(16) = 7.6$, $p < .001$. However, the interference effects did not differ between the set size conditions (happy distractor: 50 ms in both set size 3 and set size 6; angry distractor: 78 ms in set size 3, 95 ms in set size 6), $t < 1$.

Comparing facilitation and interference between happy and angry faces showed similar results as in the mean RT: In the set size 6 condition, happy and angry faces showed both similar facilitation effects and interference effects when they were presented at the target vs. non-target location, all $ps > .16$. In the set size 3 condition, the angry distractor numerically produced larger interference effects than the happy distractor (78 ms vs. 50 ms, respectively); however this difference just failed to reach significance, $t(16) = 2.0$, $p = .06$. Similarly, search times were faster for an angry target than a happy target (by 42 ms vs. 14 ms, respectively), but these differences, too, remained non-significant, $t(16) = 1.8$, $p = .094$.

Taken together, the results of the mean search times largely mimicked the findings from the mean RTs, indicating that the mean RT reflected genuine search processes. In additional analyses, we also found that the effects observed in the mean search times were mainly due to the number of fixations required to find the target, not the dwell times on the non-targets (see Appendix for a full report).

Proportion of first eye movements to the distractor

To ascertain whether the emotional distractor indeed interfered with early visual processes, we next analysed the proportion of first eye movements to the distractor (on distractor emotion trials; see Figure 3). A 2×2 ANOVA with the variables set size (3, 6) and

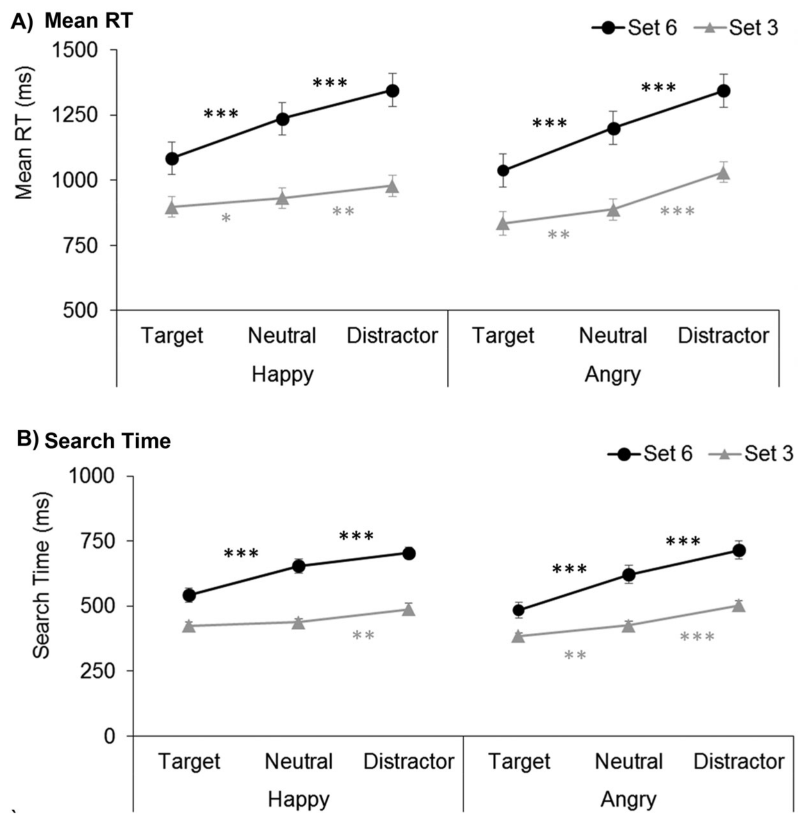

Figure 2. Results of Experiment 1: (A) Mean RT and (B) search times (the time from the onset of the search display to the first fixation on the target), depicted separately for the two set size conditions (grey, black line graphs), the to-be-ignored emotional expression (happy, angry) and the three trial types (target singleton, all-neutral, and distractor singleton trials). Mean RT and Search times were faster on target trials, when the target was the happy or angry face than on neutral trials, when the male target was presented among all-neutral female faces, and faster on these trials than on distractor trials, which contained a single happy or angry distractor. Error bars depict 1 Standard Error of the Mean and may be smaller than the plotting symbol. *$p < .05$, **$p < .01$, ***$p < .001$, as per two-tailed *t*-test.

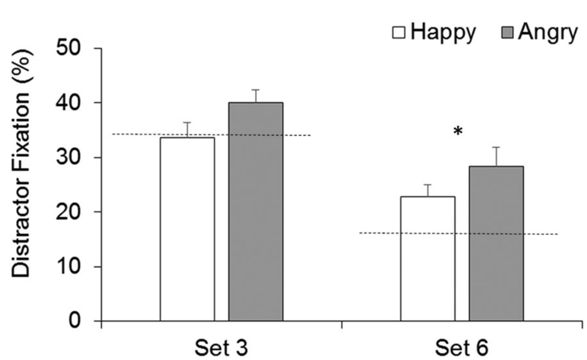

Figure 3. The proportion of first fixations on the irrelevant emotional distractor in Experiment 1. The angry distractor was selected more frequently than the happy distractor, although this difference only reached significance in the set size 6 condition (*$p < .05$, as per two-tailed *t*-test). The dashed lines depict the a priori probability of selecting the distractor by chance in random search. Distractors were selected significantly more often than chance only in the set size 6 condition. Error bars depict 1 SEM.

distractor emotion (angry, happy) showed a significant set size effect, $F(1,16) = 5.5$, $p = .033$, $\eta^2 = .25$, and a significant effect of the distractor emotion, $F(1,16) = 15.0$, $p = .001$, $\eta^2 = .49$, but no significant interaction between the variables, $F < 1$. The results are depicted in Figure 3 and show that the angry distractor attracted the gaze significantly more than the happy distractor in the set size 6 condition, $t(16) = 2.2$, $p = .047$, but not in the set size 3 condition, $t(16) = 1.5$, $p = .15$.

Moreover, to assess whether the emotional faces strongly attracted the gaze, we also compared the distractor selection rates to the a priori probability of selecting the stimulus by chance (33% in set size 3 condition; 16.7% in the set size 6 condition). The results showed that angry and happy distractors significantly attracted the gaze only in the set size 6 condition (angry distractor: $t(16) = 3.3$, $p = .005$, happy distractor: $t(16) = 2.7$, $p = .015$). In the set size 3 condition, only the angry distractor was selected more frequently than expected by chance, $t(16) = 2.9$, $p = .010$, whereas the happy distractor was selected non-significantly below chance, $t < 1$ (see Figure 3).

Distractor and non-target dwell times

To assess possible de-allocation costs, the dwell times of the first fixation on an emotional distractor (angry, happy) were compared with the dwell times of the first fixation on a neutral non-target in the respective conditions. The results of a 2 × 2 × 2 ANOVA with the variables fixated item (emotional distractor, neutral non-target), distractor emotion (happy, angry), and set size (3, 6) showed only a significant main effect of the fixated item, $F(1,16) = 4.5$, $p = .049$, $\eta^2 = .22$, and a significant interaction between the selected item and the distractor emotion, $F(1,16) = 6.6$, $p = .020$, $\eta^2 = .29$ (all other Fs < 1.4, ps > .26). Paired t-tests showed that dwell times on the angry distractor were significantly longer than on the neutral non-target in the set size 3 condition, $t(16) = 3.2$, $p = .006$, with the set size 6 condition showing a similar trend, $t(16) = 1.9$, $p = .082$. By contrast, there were no differences between the dwell times on happy distractors and neutral non-targets in any of the conditions, both ts < 1. It should be noted however that distractors were only selected on an average of 13 trials (range: 2–18), so that these results should be regarded as preliminary findings that would need further corroboration.

Masculinity ratings

Angry female faces were rated as more masculine ($M = 3.5$; 3: "somewhat masculine"; 4: "somewhat feminine") than neutral female faces ($M = 4.7$, 5: "feminine"), $t(16) = 4.6$, $p < .001$, which in turn were rated as more masculine than happy faces ($M = 4.2$), $t(16) = 2.9$, $p = .010$ (see Figure 6). These results replicate earlier findings and show that they also apply to the stimuli typically used in visual search tasks. Given these results, the stronger capture effect of angry faces in a subset of conditions could have been because angry faces were more similar to the male target.

Discussion

The results of Experiment 1 mimicked earlier findings of Hodsoll et al. (2011) and demonstrated that the effects of emotional expressions are indeed largely due to attentional capture by emotional faces. The results from the distractor dwell times moreover showed that angry faces are dwelt on for longer than neutral faces, indicating that de-allocation from angry distractor faces may additionally contribute to distractor interference by negative emotions (e.g., Belopolsky et al., 2011; Fox et al., 2001). Happy face distractors showed no such effects. However, the corresponding data need to be interpreted with some caution, as the number of distractor fixations was very low.

By contrast, the results showed no evidence that processing of negative affect takes longer. In this case, we should have observed reliable facilitation for angry faces in the mean search times that are eliminated or reduced in the mean RT (as angry faces take more time to be processed after being selected). By contrast, the results showed the opposite trend, of larger facilitation effects in the mean RT (of 101 ms) than in the mean search times (76 ms).[1] Hence, the previous failure to find facilitation effects for angry target faces cannot be attributed to peculiarities of processing negative affect.

Instead, both stronger capture by angry faces and the failure to find significant facilitation with emotional targets probably have to be attributed to the use of sparse displays containing only three items. Both the mean RT and the mean search times predominantly showed facilitation effects in the set size 6 condition which were much reduced or absent in sparser displays containing three items. Moreover, assessing the proportion of first fixations on the distractor showed that selection of the happy distractor was at chance level in the set size 3 condition, whereas it was selected significantly above chance level in the set size 6 condition. Taken together, these results support the hypothesis that sparsely populated displays are not ideal for detecting facilitation effects of emotional targets.

There was also some indication that angry faces attracted the gaze more strongly than happy faces. However, these results cannot be interpreted in favour of the threat detector hypothesis (or against an ally detector). As shown by the ratings, angry female faces were perceived as more masculine (see also Hess et al., 2009) and, hence, were more similar to the male target face than the happy faces. Hence, it is possible that angry faces attracted attention and the gaze more strongly because they were perceptually more similar to the target, not because of their affective content (e.g., Folk & Remington, 1998).

Although perceptual similarity may have modulated capture by angry faces (e.g., Duncan & Humphreys, 1989), it is interesting that angry (target-similar) and happy (target-dissimilar) distractors still had strikingly similar effects on attention and the gaze. In the set size 6 condition, happy and angry faces in fact affected attention and eye movements to a similar extent, and both led to significant facilitation and interference effects. These results indicate that target similarity can only explain a modest proportion of the effect of emotional faces. In line with the affective hypothesis, the present data show that emotional faces can attract attention even when they are dissimilar from the target and irrelevant to the task. However, as will be discussed in more detail below, these results do not yet allow ruling in favour of the affective hypothesis.

Experiment 2

Experiment 1 established that emotional faces can attract attention and the gaze when they are irrelevant to the task. However, the results cannot yet be interpreted in support of the affective hypothesis. First, both in the study of Hodsoll et al. (2011) and Experiment 1, the irrelevant emotional singleton was actually predictive of the target location, as the target had an emotional expression on 50% of all trials (when an emotional face was present). Hence, it is possible that attention was allocated to emotional faces because they were predictive of the target (e.g., Turatto & Galfano, 2001; Yantis & Egeth, 1999).

Second, the results of Experiment 1 are still consistent with the view that the emotional faces may have attracted attention because of their unique perceptual features. Of note, previous results and Experiment 1 so far only show that a singleton face that differs in its emotional expression from other faces can attract attention. However, it is possible that the same effects would be observed for any face that is a *singleton*, i.e., that differs in a facial feature from the other faces (e.g., gender). In fact, previous studies have shown that attention can be tuned rather broadly to stimuli that deviate from other stimuli, which will render us more vulnerable to distraction by singletons from other stimulus dimensions (Bacon & Egeth, 1994; Folk & Anderson, 2010). For instance, when searching for a target that can be either red or green, attention can be tuned broadly to all colour deviants, so that attention is also attracted to blue distractors even when the target is never blue (e.g., Folk & Anderson, 2010; Harris, Becker, & Remington, 2015). In Experiment 1 and previous studies, it is possible that attention was tuned rather broadly to a facial attribute of the target that was (accidentally) also a feature of the emotional distractors (but not of the nontargets). In this case, capture by the emotional distractors would not have been due to the affective contents of the faces, but to broad top-down tuning of attention to a deviant facial attribute.

Experiment 2 remedied these potential shortcomings by implementing two changes. First, we rendered emotional expressions completely irrelevant by presenting the irrelevant attribute always equiprobably at all locations, so that they were truly non-predictive of the target location. Thus, if emotional faces attracted attention in previous studies and Experiment 1 because they were all predictive of the target location (50% valid), then none of the distractors in Experiment 2 should attract attention as they were now all non-predictive of the target location.

Second, to check whether the results of Experiment 1 and previous studies were due to broad top-down tuning of attention to a facial attribute, we swapped the target and distractor features in a separate block, so that participants had to search for an emotional face (e.g., angry face), while ignoring a single male distractor. Thus, if previous results were due to broad top-down tuning to a facial feature, the male control distractor should also attract attention in search for (one of the) emotional faces. Moreover, one advantage of this design is that it allows testing the effects of irrelevant distractors when the search displays were absolutely identical and thus, free of stimulus-driven confounds (e.g., Becker, Anderson, et al., 2011; Frischen et al., 2008).

The critical conditions were all blocked, resulting in four search conditions: search for male target in the presence of an angry vs. happy distractor, and search for a happy or angry target in the presence of a male distractor. To ensure that sufficient trials were available for a more reliable estimate of disengagement effects, only the set size 6 condition was used, and a distractor was presented on every trial.

Methods

Participants

Twenty new participants participated in Experiment 2. Three of them were excluded because they failed to select the target on more than 20% of all trials. The remaining 17 participants consisted of 14 females, three males and had a mean age of 22 years (*SD* = 2.85, range: 19–31 years).

Stimuli, design and procedure

Experiment 2 was identical to Experiment 1, with the following exceptions. First, the two set size 3 conditions from Experiment 1 were replaced with two blocked set size 6 conditions in which observers searched for either an angry or happy female target face, and had to ignore an irrelevant male singleton. Thus, Experiment 2 consisted of four blocked conditions, in which observers searched for a male target among female non-targets and ignored a happy vs. angry facial expression or, vice versa, searched for a happy or angry target while ignoring a single male distractor. Moreover, the all-neutral trials were omitted, and the singleton distractor appeared with equal probability at the target location and each non-target location (16.7% target singleton trials). Each block comprised 192 trials (32 target singleton trials), and the order of blocks was chosen randomly for each participant.

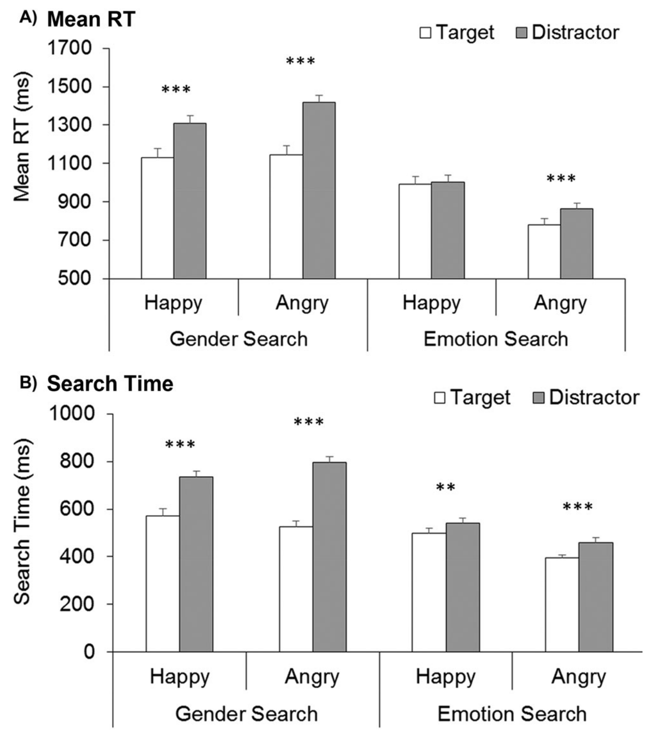

Figure 4. Results of Experiment 2: (A) Mean RT and (B) search time (to the first fixation on the target), depicted separately for trials in which the singleton (male, angry, happy) was at the target location (white histograms) or the distractor location (grey histograms). The angry and happy distractors modulated mean RT and search times more strongly than the male control distractor in search for an emotional target. Error bars depict 1 SEM. **p* < .05, ***p* < .001, ****p* < .00001, as per two-tailed *t*-test.

Results

Data

Removing RT outliers (< 300 or > 3000 ms) from all RT analyses resulted in a loss of 0.69% of all data. Removing trials without any detectable fixations on the target from the analysis of eye movement data resulted in an additional loss of 0.59% of all data. Trials with an incorrect manual response were excluded from the analysis of mean RT and eye movement parameters (2.63% of all data).

Mean RT

The mean RT in Experiment 2 are depicted in Figure 4 (A). A 2 × 2 × 2 ANOVA with the variables search task (gender, emotional expression), emotion (angry vs. happy face in the display), and trial type (emotional target vs. distractor) showed that mean RT were significantly faster in search for an emotional target than a gender target, $F(1,16) = 51.5$, $p < .001$, $\eta^2 = .76$, and faster when the singleton was at the target rather than a distractor position, $F(1,16) = 140.2$, $p < .001$, $\eta^2 = .90$, whereas the differences between angry and happy faces just failed to reach significance, $F(1,16) = 4.2$, $p = .058$, $\eta^2 = .21$. The two-way interactions were all highly significant as well (search task × emotion: $F(1,16) = 28.1$, $p < .001$, $\eta^2 = .64$, emotion × trial type: $F(1,16) = 23.2$, $p < .001$, $\eta^2 = .59$; search type × trial type: $F(1,16) = 72.2$, $p < .001$, $\eta^2 = .82$), whereas the three-way interaction remained non-significant, $F < 1$.

As shown in Figure 4(A), in search for a gender target, the emotional (happy or angry) singleton face modulated mean RT more strongly than the male singleton face in search for an emotional (happy or angry) face. To formally compare the emotional distractors with the control distractors, we computed the *validity effects* for each of the conditions (mean RT on emotional distractor trial minus mean RT on emotional target trial, and mean RT on male distractor trial minus mean RT on male target trial, respectively). The results showed that both the happy and angry irrelevant singleton faces modulated RTs significantly more strongly than the male singletons in the presence of both happy faces, $t(16) = 7.4$, $p < .001$, and angry faces, $t(16) = 6.2$, $p < .001$. In addition, in search for the male face, the angry singleton face had larger effects on RT (validity effect: 274 ms) than the happy singleton face (validity effect: 180 ms), $t(16) = 3.3$, $p = .004$. In search for emotion, the male singleton had significantly larger effects on RT in search for the angry target (validity effect: 70 ms) than in search for the happy target (validity effect: 8 ms), $t(16) = 18.2$, $p < .001$. Taken together, these results establish that emotional distractors modulate search to a larger extent compared with other singletons.

The failure of the male singleton face to strongly attract attention also cannot be attributed to the fact that it was presented across two blocks, and thus was more frequently encountered. The results remained the same when only the first block with the male singleton face was entered into the comparisons. Moreover, assessing training effects by comparing mean RT across the first vs. second half of each block revealed only a significant main effect of training, $F(1,16) = 10.9$, $p = .004$, $\eta^2 = .41$, but no interaction with any of the other variables, all Fs < 2.0; all ps $> .17$. These results rule out an explanation in terms of habituation or training effects, and indicate that emotional faces genuinely attract attention to a larger extent than other singletons such as male faces.

Search times

The same $2 \times 2 \times 2$ ANOVA computed over the mean search times showed significant main effects of the search task (emotion, gender), $F(1,16) = 92.0$, $p < .001$, $\eta^2 = .85$, emotion (angry, happy), $F(1,16) = 15.8$, $p < .001$, $\eta^2 = .50$, and trial type (at target vs. distractor position), $F(1,16) = 169.7$, $p < .001$, $\eta^2 = .91$. In addition, all two-way interactions were significant (search type $\times$ emotion: $F(1,16) = 31.4$, $p < .001$, $\eta^2 = .66$, emotion $\times$ trial type: $F(1,16) = 8.2$, $p = .010$, $\eta^2 = .35$; search task $\times$ trial type: $F(1,16) = 84.1$, $p < .001$, $\eta^2 = .84$), as well as the three-way interaction, $F(1,16) = 13.9$, $p = .002$, $\eta^2 = .47$.

Follow-up analyses comparing validity effects between the conditions revealed that both the happy and angry singleton faces modulated search times more strongly than the control male face, both when a happy face was present, $t(16) = 8.3$, $p < .001$, as well as with an angry face, $t(16) = 7.9$, $p < .001$. Moreover, in search for the male face, the angry face modulated search significantly more strongly (validity effect: 248 ms) than the happy face (validity effect: 161 ms), $t(16) = 3.8$, $p = .002$. By contrast, in search for emotion, the male singleton distractor did not elicit a stronger distraction effect in search for angry targets (validity effect: 44 ms, $t(16) = 5.4$, $p < .001$) than in search for happy targets (validity effect: 38 ms, $t(16) = 3.0$, $p = .009$), $t < 1$.

Proportion of first fixations on distractor

Figure 5(A) depicts the proportion of first eye movements to the emotional singleton face and the male control face. A 2×2 ANOVA with the variables search type (emotional expression, gender) and emotion (angry, happy) showed no significant main

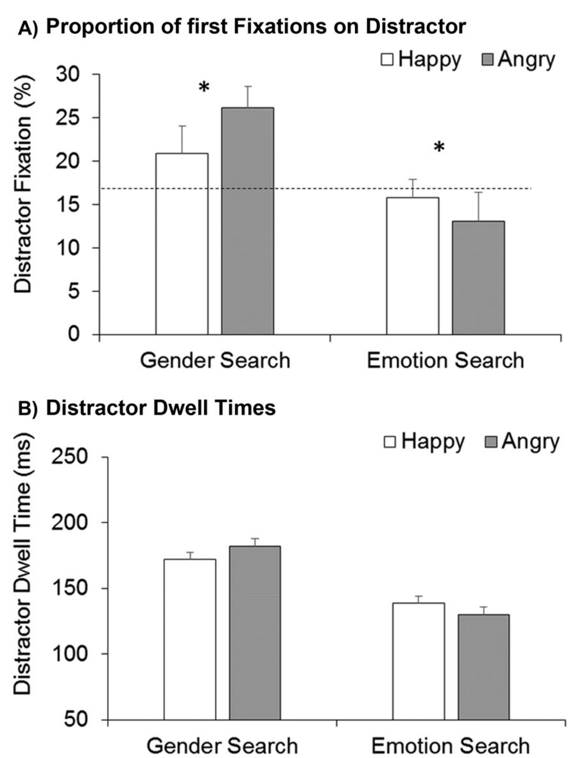

Figure 5. (A) The proportion of first fixations on the irrelevant distractor in Experiment 2. Only the emotional distractors were selected significantly more frequently than chance (indicated by the dashed line), and angry distractors were selected more frequently than happy distractors (*$p < .05$, as per two-tailed t-test). (B) The distractor dwell times showed longer dwell times on the emotional distractors (happy, angry) than the male control distractors, but no differences between different emotional faces (happy, angry). Error bars depict 1 SEM.

effect of emotion, $F < 1$, but of search type, $F(1,16) = 41.4$, $p < .001$, $\eta^2 = .72$, as well as a significant search type × emotion interaction, $F(1,16) = 9.6$, $p = .007$, $\eta^2 = .38$. In line with the search time results, the emotional faces attracted the gaze significantly more strongly than the male control face, and these effects were observed both with a happy face, $t(16) = 3.4$, $p = .004$, and with an angry face, $t(16) = 5.3$, $p < .001$. In addition, the angry distractor attracted the gaze more strongly than the happy distractor, $t(16) = 2.3$, $p = .034$, and the male distractor attracted the gaze more strongly in search for happy targets than angry targets, $t(16) = 2.1$, $p = .047$.

When comparing the distractor selection rates with the probability of selecting the distractor by chance (16.7%), both the happy and angry distractor were selected significantly more frequently than chance, $t(16) = 4.9$, $p < .001$ and $t(16) = 4.7$, $p < .001$, respectively. By contrast, the male distractor was not selected with higher-than-chance probability. In search for the angry target, the male control distractor was even selected with lower-than-chance probability, $t(16) = 2.5$, $p = .024$ (see Figure 5(A)).

Distractor dwell times

Figure 5(B) depicts the mean dwell times on each distractor type. The same 2 × 2 ANOVA computed over the distractor dwell times showed only significant differences between the two search tasks, $F(1,16) = 66.5$, $p < .001$, $\eta^2 = .80$, all other Fs < 3.4, ps $> .16$. As shown in Figure 5(B), the gaze dwelt significantly longer on the emotional distractors ($M = 165$ ms) than on the male control distractors ($M = 124$ ms), both for happy distractors, $t(16) = 6.4$, $p < .001$, and angry distractors, $t(16) = 6.6$, $p < .001$. However, there was no dwell time difference between the happy and angry distractor, $t(16) = 1.5$, $p = .14$, or between the male distractors in search for happy or angry faces, $t(16) = 1.5$, $p = .14$.[2]

To test whether the male singleton distractor also affected the dwell times, we additionally compared the dwell times of all singleton distractors (male, happy, angry) to the dwell times of the first fixations on a neutral non-target. The results showed that, on average, dwell times were 13 ms shorter on non-target faces ($M = 132$ ms) than on the irrelevant singleton distractor ($M = 145$ ms). Specifically, non-target fixations were 7 ms and 10 ms shorter compared with the male distractor in search for a happy target, $t(16) = 2.6$, $p = .020$, and in search for the angry target, $t(16) = 2.5$, $p = .022$. Non-target fixation durations were also 13 ms and 19 ms shorter compared with the respective happy and angry distractors in search for a male target, $t(16) = 3.1$, $p = .007$, and $t(16) = 5.4$, $p < .001$, respectively. These results indicate that disengagement is delayed for all singleton faces, including emotionally neutral singleton distractors, whereby disengagement is selectively more delayed for emotional distractors.[3]

Masculinity ratings

To assess the possible effect of perceived masculinity on the results (see Figure 6, right), the observers' ratings were analysed with a 2 × 3 ANOVA comprising the variables gender (male, female) and emotion (angry, neutral, happy). The results showed a significant main effect of gender, $F(1,16) = 173.0$, $p < .001$, $\eta^2 = .92$, emotion, $F(2,32) = 25.5$, $p < .001$, $\eta^2 = .62$, as well as a significant interaction between the variables, $F(2,32) = 7.4$, $p = .003$, $\eta^2 = .32$. The interaction reflected that masculinity ratings differed more strongly for the female faces than the male faces (see Figure 6). Specifically, female angry faces were perceived to be significantly more masculine than neutral faces, $t(16) = 7.3$, $p < .001$, which in turn were judged to be more significantly masculine than female happy faces, $t(16) = 4.8$, $p < .001$. For the male faces, an angry face was also perceived to be more masculine than a neutral face, $t(16) = 3.8$, $p = .002$. However, neutral male faces did not differ from male happy faces in perceived masculinity, $t(16) = 1.9$, $p = .071$.

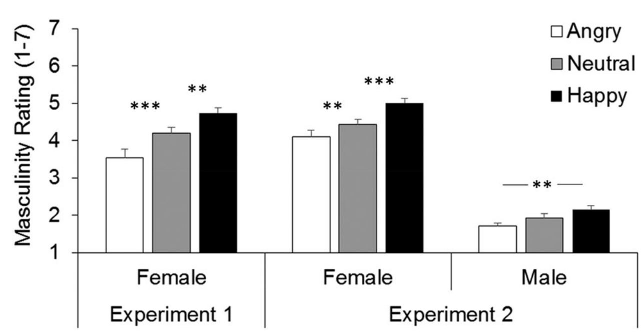

Figure 6. Subjective ratings of the masculinity of angry, neutral, and happy female faces (left) from Experiment 1, and the female and male faces of Experiment 2 (scale: 1 = very masculine; 7 = very feminine). Female angry faces were rated as more masculine and female happy faces as less masculine than neutral faces, whereas among the male faces, angry faces were only rated as more masculine than happy faces. Error bars depict 1 SEM. **$p < .01$, ***$p < .001$, as per two-tailed t-test.

Comparison of Experiment 1 and Experiment 2

The proportion of first eye movements to the emotional distractors seemed slightly reduced in Experiment 2, where the emotional expression was truly non-predictive of the target location, and distractors were presented much more frequently (on 100% of trials instead of 33% of trials). In Experiment 2, happy and angry distractors were selected on 20% and 24% of all trials, compared with 23% and 28% in the set size 6 condition of Experiment 1. However, independent-samples *t*-tests revealed no significant differences in distractor selection rates between the experiments, neither in the first eye movement to the happy distractor, $t(32) = 1.1$, $p = .29$, nor in those to the angry distractor, $t(32) = 1.2$, $p = .26$. The results indicate that the frequency of presenting distractors (33% in Experiment 1 vs. 100% in Experiment 2), and the differences in the predictiveness of the distractor (50% in Experiment 1 vs. non-predictive in Experiment 2) did not significantly modulate the effects of emotional distractor faces.

Discussion

The results of Experiment 2 showed that emotional distractors attract the gaze more strongly than control distractors that differ in a non-emotional facial feature. There was no indication that the control distractor attracted the gaze, as it was not selected above chance level. Still, the irrelevant male distractor held the gaze for slightly longer durations than the neutral female non-target faces. This shows that the male distractor was indeed perceived as different, indicating that the male control distractor worked as intended. The failure of the male distractor to attract attention also cannot be attributed to habituation or training effects (see above). In this regard, the fact that the male control distractor did not attract attention allows ruling out the perceptual account, that emotional expressions attracted attention in Experiment 1 because observers had broadly tuned attention to deviant perceptual attributes (e.g., Bacon & Egeth, 1994; Folk & Anderson, 2010; Harris et al., 2015). It is also interesting to note that the male distractor failed to attract attention in search for angry female face, even though the female angry face is somewhat similar to a male face (see rating results of Experiment 1). With this, the results of Experiment 1 and Experiment 2 cannot be attributed to perceptual similarity, or to broad top-down tuning of attention to deviant facial attributes (e.g., Bacon & Egeth, 1994; Duncan & Humphreys, 1989).

A second important finding of Experiment 2 was that the emotional distractors still attracted attention and the gaze, even though they were completely non-predictive of the target location, and presented frequently. This shows that previous results were not due to rare presentations of emotional faces, or the fact that the emotional face was slightly predictive of the target (e.g., 50% instead of 33% in Experiment 1, and the study of Hodsoll et al., 2011). In fact, a comparison of Experiment 1 and Experiment 2 revealed no significant differences between the experiments, indicating that capture by complex stimuli such as emotional expressions are unlikely to be due to top-down search strategies to attend to emotions.

Third, Experiment 2 permitted a better assessment of the contributions of disengagement processes to overall distractor effects and revealed that emotional distractors do not only affect early, attentional processes but also later processes. Specifically, the dwell times on emotional distractors were on average 41 ms longer than on male control distractors. These results reflect a large increase in the mean dwell times and indicates that late, post-selectional processes can contribute substantially to the overall interference effect observed in later measures such as the search times and mean RT.

General discussion

The present study provides clear evidence that emotional expressions of anger and happiness can attract attention and hold the gaze even when they are irrelevant to the task. Previous studies using the irrelevant singleton paradigm (e.g., Yantis & Egeth, 1999) often failed to find significant facilitation effects when an irrelevant emotional expression was associated with target, and/or reported interference only for angry, but not happy emotional expressions (e.g., Hodsoll et al., 2011; Horstmann & Becker, 2008; Huang et al., 2011). These results were often interpreted as evidence for a threat detector that produced stronger capture for angry emotional faces and/or as evidence that angry faces hold attention for longer, which neutralizes facilitation effects (e.g., Hodsoll et al., 2011). However, as argued in the introduction, these results do not provide clear evidence for attentional capture by emotional faces, as they are also consistent with non-specific interference or filtering, as well as later processes contributing to the interference effects (e.g., disengagement).

In the present study, we used measures that allowed distinguishing between attentional capture and later disengagement (e.g., Theeuwes, Atchley, & Kramer, 2000). We found that emotional faces can attract attention and hold the gaze for longer than neutral faces, but there was no evidence that angry and happy faces exert different effects on capture or disengagement. Interestingly, we observed both the theoretically important facilitation effect, as well as interference effects, for both happy and angry expressions, which were however confined to more densely populated displays (set size 6), and did not occur in sparsely populated displays (set size 3; replicating the results of Hodsoll et al., 2011).

Sparse displays may be insensitive to facilitation effects because the a priori probability of selecting the target in a sparsely populated display is already quite high. Especially when an attribute does not strongly capture attention but only moderately guides attention, a high a priori probability of selecting the stimulus would render the paradigm rather insensitive to detect guidance. In line with this explanation, the results of Experiment 1 indicated that emotional faces do not strongly capture attention but only moderately guide attention (see Horstmann & Becker, 2008, for the difference between attentional capture and misguidance effects). Similarly, there were strong set size effects for finding the search target, including when it was a happy or angry face, indicating that it was not selected as the first item on each trial, but only after searching through a subset of the neutral non-target faces. Taken together, these results indicate that emotional faces do not strongly attract attention (see Figures 3 and 5(A); Todd & Kramer, 1994). Such moderate attentional effects are more likely to be observed when the a priori probability of selecting an item is low (i.e., in higher set size conditions), and it is possible that a similar explanation can also explain the lack of significant facilitation effects in in other studies that used sparse displays with different paradigms (e.g., dot-probe task; Mathews, Mackintosh, & Fulcher, 1997; Yiend & Mathews, 2001).

Another important insight is that both early pre-attentive processing gains and later post-selectional disengagement costs contributed to the net effects of emotional distractors. In line with previous results showing similar effects with schematic faces and/or in sparser stimulus displays (e.g., Becker, Horstmann, et al., 2011; Belopolsky et al., 2011), we found that emotional faces hold the gaze for longer than neutral faces in classical visual search tasks with photorealistic faces (see Figures 4(B), 5(A) and 5(B)). However, contrary to Hodsoll et al.'s (2011) hypothesis, disengagement costs were not limited to angry faces or the processing of negative affect, but applied similarly to angry and happy faces. The finding that disengagement costs contribute substantially to the interference effect highlights the importance to use measures that can actually distinguish between capture and disengagement, and caution against the common approach to infer attentional capture from interference effects in late measures such as the mean RT.

The two perhaps most important findings of the present study concern the possible involvement of top-down effects and perceptual factors in mediating attentional effects of emotional faces. Specifically, previous studies could not rule out that the effects of emotional expressions were mediated by the perceptual similarity between target and distractors (e.g., Duncan & Humphreys, 1989), or by observers tuning attention rather broadly to facial attributes that distinguished the target from the non-targets (e.g., Bacon & Egeth, 1994). In addition, it remained an open question whether rendering an emotional face predictive of the target would boost capture by emotional faces. In the present study, we found that top-down strategies play only a minor role. First, we found that rendering emotional faces more or less predictive of the target (compare Experiment 1 and Experiment 2) did not alter the results. Similarly, presenting emotional faces rarely or frequently (on only 33% of all trials vs. 100% of all trials) did not significantly affect the results. These findings contrast with previous work showing that presenting an irrelevant elementary feature such as a colour or motion distractor with varying frequency or informativeness for the search target will produce large changes in attentional capture (e.g., Harris et al., 2015; Retell, Becker, & Remington, 2016; Yantis & Egeth, 1999; Wolfe, 1998). This indicates that effects of presentation frequency and/or predictiveness may be limited to elementary features that can strongly guide attention, and may not generalize to more complex stimuli such as emotional faces that guide attention only weakly. Naturally, this explanation would warrant further research; however, it seems to be clear that top-down search strategies play, at most, a minor role in search among photographic faces.

Similarly, capture by emotional faces is unlikely to be due to the perceptual similarity of emotional faces to the search target, or broad top-down tuning to distinguishing features (e.g., Duncan & Humphreys, 1989; Wolfe, 1994). In line with previous research we found that male faces are perceptually more similar to angry female faces than happy female faces (e.g., Hess et al., 2009). However, this effect is unlikely to account for the often-reported finding that angry faces attract attention more strongly than happy faces (e.g., Hodsoll et al., 2011). First, we observed that the target-dissimilar, happy face still reliably attracted attention and the observer's gaze (see Experiment 1). Second, the results of Experiment 2 showed that a male control distractor fails to attract attention in identical displays, when the target is an angry female face (i.e., when target-distractor similarity is held constant). The findings render it very unlikely that the effects of emotional expressions can be attributed to a top-down, feature-based attentional mechanism that determines attentional capture by the perceptual similarity of target and distractor (e.g., Duncan & Humphreys, 1989; Folk & Remington, 1998; Martinez-Trujillo & Treue, 2004; Wolfe, 1994).

Similarly, the results also argue against the view that attention was broadly tuned to all facial attributes that rendered the target face different from the non-targets. Such broad search settings have been observed in previous studies with elementary features such as colour and shapes (e.g., Bacon & Egeth, 1994; Folk & Anderson, 2010; Harris et al., 2015). Yet, if attentional effects of emotional faces were entirely due to such a broad attentional tuning strategy, then the male distractor should also have attracted attention in search for the emotional faces, contrary to our findings. Taken together, the present results thus rule out two prominent perceptual explanations (similarity effects and broad tuning), and show that emotional expressions have effects over and above those associated with other perceptually salient features in visual search.

In conclusion, the results of the present study showed that completely irrelevant emotional distractors can attract the gaze and prolong disengagement, even when they are dissimilar from the target, and their effects cannot be explained by broad top-down attentional settings. Moreover, the finding that a control distractor with a neutral expression completely failed to attract attention indicates that emotional faces indeed have a special ability to attract our attention that does not generalize to all kinds of perceptual attributes.

We may be tempted to conclude that, therefore, emotional faces attract attention in a bottom-up, stimulus-driven manner, independent of the observer's top-down search goals. However, although the findings are in line with this hypothesis, as well as the affective hypothesis, it is notoriously difficult to rule out confounding perceptual factors. First, it is still possible that attention was automatically attracted to a perceptually salient feature inherent in the emotional expressions, such as, for instance, visible teeth (e.g., Horstmann et al., 2012; Itti & Koch, 2000; Savage, Lipp, Craig, Becker, & Horstmann, 2013). Second, it is possible that the male control distractor failed to attract attention because attention could be tuned to more salient features in search for the emotional faces (e.g., visible teeth) that were not shared by the male control distractor. This would be in line with previous findings showing that in singleton search, the more salient singleton captures attention when the task is to search for the less salient singleton, whereas the less salient singleton does not capture attention when the task is to find the more salient singleton (Theeuwes, 1992) In turn, search for the male face may have required tuning attention to facial features that were also part of the emotional distractors (e.g., lines in the eyebrow region). That is, asymmetries in the affordances of how attention can be tuned to each face (male, emotional), or the separation of task-relevant vs. task-irrelevant features in the search display can cause asymmetries in top-down tuning that will cause asymmetrical results, even when the displays themselves are completely identical. These difficulties underlie all visual search studies and may be impossible to eradicate (especially with ecologically more valid, complex stimuli such as faces; Calvo & Nummenmaa, 2008). Still, the very weak effects of perceptual similarity found in the present study indicate that proponents of a perceptual view would need to shift their focus to different guiding attributes and/or different mechanisms of top-down tuning to explain attentional effects by emotional faces.

Notes

1. We also assessed the dwell times on the emotional targets to test Hodsoll et al.'s idea, that processing of negative affect may be more time-consuming and found no evidence that processing angry targets takes longer than processing of happy targets. In the set size 6 condition, the average target dwell time on happy faces was 248 ms, and on angry faces it was 247 ms, $t < 1$. In set size 3 condition, the gaze dwelt for 260 ms on happy targets, and for 259 ms on angry targets, $t < 1$. Thus, there was no support for the hypothesis that negative facial expressions require more processing time. Similarly, additional analyses of the mean number of non-target fixations and dwell times (see Appendix) did not show any effects that selectively applied to negative faces.
2. When the dwell times were computed for all fixations on the distractors, instead of only the first distractor fixations, the results were similar. In addition to the reported effects, the dwell times on the angry distractor ($M = 181$ ms) were longer than on the happy distractor ($M = 173$ ms), and this 8 ms difference was just significant, $t(16) = 2.1$, $p = .049$, whereas a similar difference between dwell times on the male distractor in search for the angry target ($M = 124$ ms) and the happy target ($M = 132$ ms) failed to reach significance, $t(16) = 1.9$, $p = .071$. However, an argument can be made that the first fixation dwell times provide a better estimate for de-allocation costs, as later fixations can be more strongly modulated by detection of the target.
3. The results of the dwell time analyses in Experiment 2 were based on average on 50 trials/cell (range: 19 to 91 trials), thus providing a much better estimate of the mean dwell times as in Experiment 1.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This research was supported by an Australian Research Council (ARC) Future Fellowship (FT130101282), Discovery Grant (DP170102559) and a University of Queensland Foundation Research Excellence Award awarded to Stefanie I. Becker, and a Cluster of Excellence Cognitive Interaction Technology (CITEC) (EXC 277) award funded by the German Research Foundation (DFG), and DFG-Grant HO 3248/2-1 to Gernot Horstmann.

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Appendix

The results of Experiment 1 showed that the mean RT corresponded well with the mean search times (measured from the onset of the search display to the point in time where the target was selected for the first time). These results were taken to show that the mean RT were search-related processes, not post-search processes that commence after the target has been selected. Still, it remains an open question whether the search times were determined by the number of eye movements on non-target items, or by the time dwelt on these items.

To address this question, we additionally analysed (1) the mean number of fixations on irrelevant non-target items prior to target selection, and (2) the mean dwell times of these fixations. As dwell times can be influenced by multiple different factors, including the time spent on the previous item, and the attributes of the next targeted item (e.g., Becker, 2011; Venini et al., 2014; Wu & Kowler, 2013), we only analysed the dwell time of the *first* non-target fixation in each trial (see Horstmann, Herwig, & Becker, 2016 for a similar procedure).

Results: Experiment 1

Number of non-target fixations

The mean number of fixations on non-targets was analysed with a 2 × 2 × 3 ANOVA comprising the variables of emotion (angry, happy), set size (3, 6), and trial type (all-neutral, target emotion trial, distractor emotion trial). The results revealed a significant main effect of set size, $F(1,16) = 110.7$, $p < .001$, $\eta^2 = .87$, trial type, $F(2,32) = 89.1$, $p < .001$, $\eta^2 = .85$, a significant emotion × trial type interaction, $F(2,32) = 4.0$, $p = .033$, $\eta^2 = .20$, and a significant set size × trial type interaction, $F(2,32) = 20.4$, $p < .001$, $\eta^2 = .56$, but no significant three-way interaction, $F < 1$.

As shown in Figure A1, the results showed significant facilitation and interference effects, with fewer saccades required to select an emotional target than the target in an all-neutral display, and fewer saccades in the all-neutral display than with an emotional distractor. Facilitation and interference effects were also significant across all conditions, all *ps* < .02, with the only exception of the facilitation effect in the set size 3 condition with the happy distractor, which just failed to reach significance, $p = .053$. Comparing the magnitude of facilitation and interference across the conditions revealed that the set size 6 condition again showed far larger facilitation effects (happy: 0.46 saccades, angry: 0.5 saccades) than the set size 3 condition (happy: 0.09 saccades, angry: 0.15 saccades), both *ts* > 6.7, *ps* < .001. However, the interference effects did not differ across the set size conditions, all *ts* < 1.

Comparing facilitation vs. interference revealed a trend for stronger facilitation effects than interference effects in the set size 6 condition (happy: $t(16) = 3.3$, $p = .004$; angry: $t(16) = 2.1$, $p = .05$), but no differences between facilitation and interference in the set size 3 condition, all *ts* < 2.0, *ps* > .06).

Non-target dwell times

The same ANOVA computed over the dwell times of the first fixation on a non-target showed only a significant main effect of the emotion, $F(1,16) = 7.3$, $p = .016$, $\eta^2 = .31$, and of the position of the emotional

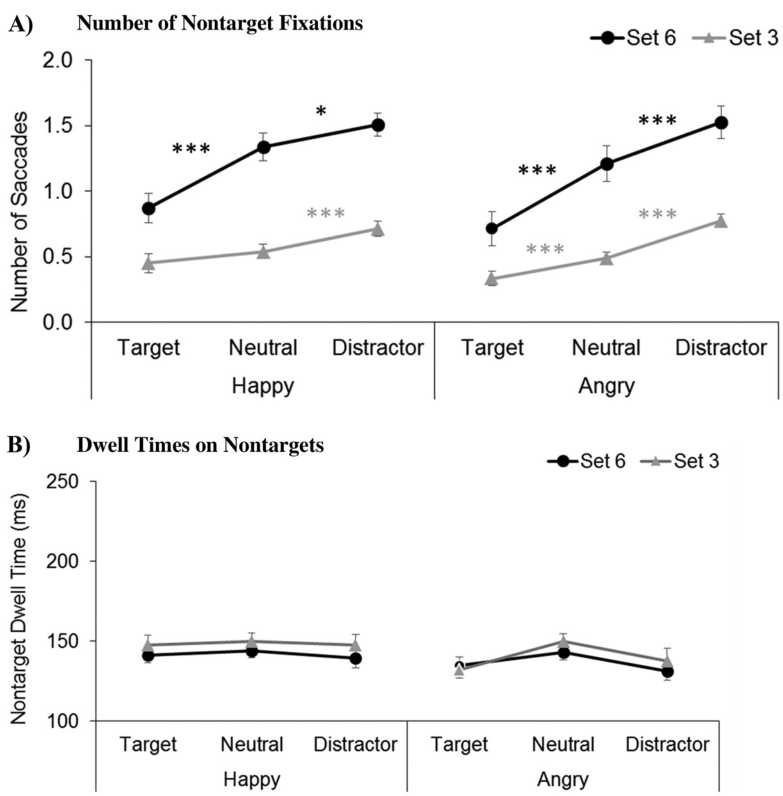

Figure A1. Results of Experiment 1: (A) Mean number of non-target fixations and (B) mean dwell times of the first non-target fixations on each trial, depicted separately for the two set size conditions (grey, black line graphs), the to-be-ignored emotional expression (happy, angry) and the three trial types (target singleton, all-neutral and distractor singleton trials). The number of non-target fixations closely mimics the results of the mean search times and mean RT observed in Experiment 1, whereas the mean dwell times did not show any significant contributions to the observed effects. Error bars depict 1 Standard Error of the mean and may be smaller than the plotting symbol. *$p < .05$, **$p < .01$, ***$p < .001$, as per two-tailed *t*-test.

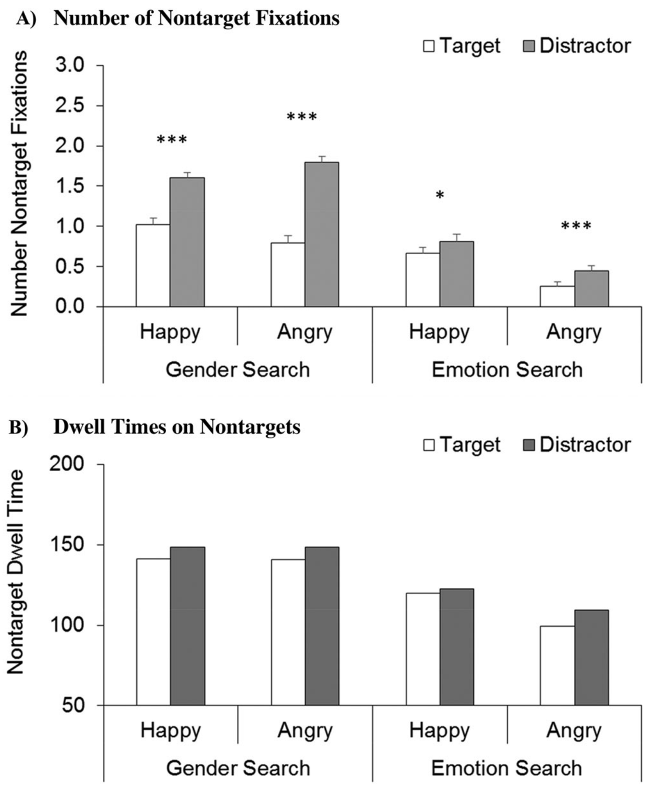

Figure A2. Results of Experiment 2: (A) Mean number of non-target fixations and (B) the mean dwell times of the first non-target fixations on each trial, depicted separately for trials in which the singleton (male, angry, happy) was at the target location (white histograms) or the distractor location (grey histograms). The results of the non-target fixations mimic the results of the search times and mean RT, with a stronger modulation by angry and happy distractors than the male control distractor. By contrast, no such effects were evident in the non-target dwell times. Error bars depict 1 SEM. *$p < .05$, **$p < .001$, ***$p < .00001$, as per two-tailed *t*-test.

distractor, $F(2,32) = 3.8$, $p = .033$, $\eta^2 = .19$, whereas the interactions all remained non-significant, all $Fs < 2.7$, $ps > .08$. Inspection of Figure A2 reveals that the fixation dwell times did not contribute to facilitation or interference effects, indicating that the effects observed in the mean RT have to be largely attributed to the probability of selecting the non-targets or distractor, not the time dwelt on non-target items.

Results: Experiment 2

Number of non-target fixations

The mean number of non-target fixations in Experiment 2 was analysed in the same way as the mean search times and mean RTs, i.e., with a 2 × 2 × 2 ANOVA comprising the variables of search task (gender, emotional expression), emotion (angry vs. happy face in the display), and trial type (emotional target vs. distractor). The results showed significant main effects of the search task, $F(1,16) = 103.6$, $p < .001$, $\eta^2 = .87$, emotion, $F(1,16) = 19.7$, $p < .001$, $\eta^2 = .55$, and the trial type, $F(1,16) = 161.5$, $p < .001$, $\eta^2 = .91$. The two-way interactions were also all significant (emotion × search type: $F(1,16) = 12.9$, $p < .001$, $\eta^2 = .45$, emotion × trial type: $F(1,16) = 11.2$, $p = .004$, $\eta^2 = .41$, search task × trial type: $F(1,16) = 77.8$, $p < .001$, $\eta^2 = .83$), as was the three-way interaction, $F(1,16) = 9.8$, $p = .006$, $\eta^2 = .38$.

Figure A2(A) suggests that the emotional distractors modulated the number of fixations more strongly than the male control distractor. To assess this possibility, we computed the validity effects (singleton at distractor position minus singleton on target position) separately for each condition and compared the validity effects. The results showed that happy and angry distractors produced stronger validity effects than the male distractor in the identical display condition, both $ts > 7.1$, $ps < .001$. However, angry and happy distractors did not differ significantly from each other, $t < 1$. Similarly, the male control distractor affected the number of non-target fixations similarly in search for happy and angry targets, $t(16) = 1.1$, $p = .29$.

Non-target dwell times

The same analysis performed over the first-pass dwell times yielded a significant main effect of the search task, $F(1,16) = 50.8$, $p < .001$, $\eta^2 = .76$, the emotion of the face, $F(1,16) = 8.6$, $p = .010$, $\eta^2 = .35$, and the position of the singleton, $F(1,16) = 18.0$, $p = .001$, $\eta^2 = .53$. Of the interactions, only the emotion × search task interaction reached significance, $F(1,16) = 8.0$, $p = .012$, $\eta^2 = .34$, all other $Fs < 1.8$, $ps > .19$. As shown in Figure A2(B), the dwell times were shorter in search for an emotional target (with male distractor) than in search for the male target (with an emotional distractor), and dwell times tended to be slightly shorter on target singleton than distractor singleton trials.

Importantly, however, the non-target dwell times did not contribute differentially to the magnitude of the distractor effect across conditions (as also shown in the non-significant search type × position interaction). With this, the larger distractor effect of the emotional faces has to be attributed to the probability of selecting emotional faces, rather than the dwell times on irrelevant items.

Discussion

Taken together, the results of the additional analyses bolster the earlier conclusion, drawn from the inspection of distractor selection rates and distractor dwell times, that emotional faces mainly modulate search performance by affecting the probability of selecting the target. In turn, the alternative explanation, that emotional faces affect mainly post-selectional processes that commence after selection of an item, is not supported by the results.

It is interesting to note that non-target dwell times were modulated by the search task, whereas they were largely unaffected by the placement of an emotional face vs. different-gender face (i.e., at the target position vs. a distractor position). With this, the shorter dwell times in search for emotional faces probably reflect an adaptation to difficulty of each search task. Possibly, emotional faces are easier to recognize once they are fixated than a gender singleton, which reduces the time needed to process each item. Hence, the dwell times were adapted at the level of the search block, but remained largely unaffected by the exact composition of the search display and, specifically, the placement of the singleton face. With this, the non-target dwell times have little explanatory value in explaining distracting effects of emotional faces and, more generally, singleton faces, in visual search.

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