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More Efficient Visual Search for Happy Faces May Not Indicate Guidance, but Rather Faster Distractor Rejection: Evidence From Eye Movements and Fixations

Gernot Horstmann
Bielefeld University

Stefanie I. Becker
University of Queensland

The visual search paradigm has been used in emotion research to examine the relation between facial expressions of emotion and attention. Here, the better performance in a search for one facial expression category (e.g., a happy face) compared to a second category (e.g., an angry face) has been often interpreted as indicating better guidance of attention. Better guidance of attention in turn indicates that some aspect of the facial expression can be used preattentively, that is, while focused attention is directed elsewhere in the visual field. This view has been criticized because better performance may also mean better distractor rejection independently of guidance. The present study uses eye tracking to disentangle the two variables. The results show better search performance with a happy than angry face as the target. Facial emotion also influenced the time the eyes fixated a stimulus (dwelling), but not guidance related variables of search performance. A linear regression moreover showed that dwelling accounted for large amounts of variance in the overall search times. Overall, the results present clear-cut evidence that differential search performance does not need to indicate differential guidance, but may also be explained by postselective factors that influence the dwelling on stimuli. The broader implication of this demonstration is that results from the visual search paradigm have to be interpreted with caution, and that better search performance cannot be directly interpreted as an indicator of preattentive guidance of attention.

Keywords: emotion, attention, visual search, faces

Since Hansen and Hansen's (1988) seminal paper on a search advantage for angry faces, the visual search paradigm carried the promise of unveiling the extent to which emotion is processed preattentively. These authors presented an angry target among multiple happy nontarget faces or a happy target among multiple angry nontargets, and found search to be efficient for angry targets but inefficient for happy targets. Following the logic of Feature Integration Theory (Treisman & Gelade, 1980), they reasoned that angry faces (but not happy faces) are processed preattentively, that is, prior to the selective processing associated with attention, and with spatially unlimited resources.

The preattentive emotion hypothesis was received with high interest for historical and systematic reasons. Historically, the hypothesis resonated with the medieval idea—prominently featured in Freud's work—emphasizing a schism between cognition on the one hand and dynamic factors such as emotion and motivation on the other hand. Freud's famous contribution to this line of thinking was his emphasis on the independence and power of dynamic factors for mental life. Proof that emotion is processed independently from one of the central cognitive variables—attention—would support this Freudian conception. An important systematic reason was that a proof of preattentive processing of emotion would put affect not in the second row after cognition, but on the front row, on a par with cognition. A further line of theorizing that drove the interest in visual search experiments on emotional stimuli was the evolutionary primacy of negative affect. Not attending to threat cues comes with higher costs than not attending to cues to nonthreatening events and in particular to positive outcomes. Thus, demonstrating that negative cues can guide attention away from nonthreatening cues would indicate that the human processing system is well designed by evolution, and that modern man still has a Pleistocene brain, well adapted to the hunter and gatherer ecological niche, but not necessarily to present societies' demands.

Modern day theorizing about cognition and emotion has moved away from these preponderances. Dynamic factors do not need to be active before elementary operations of perception and attention have been performed to have a special status that is rather distinct from cognition (which was actually empathized already by Neisser (1967) in his eponymous book *Cognitive Psychology*). And that modern humans use a brain that is adapted to the Pleistocene and

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Gernot Horstmann, Department of Psychology and CITEC, Bielefeld University; Stefanie I. Becker, School of Psychology, University of Queensland.

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Correspondence concerning this article should be addressed to Gernot Horstmann, Department of Psychology, Bielefeld University, P.O. Box 100 131, 33 501 Bielefeld, Germany, E-mail: gernot.horstmann@uni-bielefeld.de

not to the modern world is nowadays widely accepted, and does not need evidence of ultrafast detection of negative cues.

Yet a considerable amount of research has been conducted on positive and negative stimuli and how fast these stimuli are detected during visual search (e.g., Eastwood, Smilek, & Merikle, 2001; Fox et al., 2000; Horstmann, 2007; Horstmann, Lipp, & Becker, 2012; Horstmann, Scharlau, & Ansorge, 2006; Nothdurft, 1993; Öhman, Lundqvist, & Esteves, 2001; Tipples, Atkinson, & Young, 2003; Reynolds, Eastwood, Partanen, Frischen, & Smilek, 2009; White, 1995; for reviews see D. V. Becker, Anderson, Mortensen, Neufeld, & Neel, 2011; Frischen, Eastwood, & Smilek, 2008). The visual search paradigm (Neisser, 1964; Treisman & Souther, 1985; Wolfe, 1998), a laboratory model of visual search in natural environments, presents a collection of stimuli, with the task to detect a prespecified target. Most of the stimuli are nontargets (often called distractors). In inefficient search, the time to detect the target increases strongly with the number of nontargets in the display. In efficient search, by contrast, the target is detected very fast, independently of the number of nontargets. The latter case is often interpreted as indicating that the target draws attention to itself. In particular, it is assumed that features of the target are processed preattentively (before attention) and that the result of this preattentive processing can guide attention to its position. In the former case of inefficient search, search may not be informed by preattentive processing, and attention would be moved rather blindly to stimuli in the display, which are in turn attentively analyzed and categorized into nontargets or targets. When the guidance provided by the target is weak, intermediate forms between clearly efficient and clearly inefficient search result.

In the context of emotion research, search efficiency differences have been accordingly interpreted as indicating differential amounts of guidance provided by a particular emotional target, for instance, an angry face target among happy faces nontargets (e.g., Eastwood et al., 2001; Horstmann & Bauland, 2006). This is completely consistent with guidance-based models of visual search, such as Guided Search (GS; Wolfe, 1994; 2007; Wolfe, Cave, & Franzel, 1989) or the Target Acquisition Model (TAM; e.g., Zelinsky, 2008). For example, in GS, the assumed characteristics of the target (the representation of which is often called the target template following Duncan & Humphreys, 1989) interact with preattentive information extracted in parallel from the search display. For each location, evidence for a target is accumulated in an activation map, where the amount of activation at one location corresponds to the evidence that the location contains the target. A gradient descent algorithm is used to schedule the sequential shifts of attention. A high peak in the activation map at the target's location thus leads to an early focusing of attention on that location, and search is efficient. When some of the nontargets share features with the target, multiple peaks arise in the activation map, and because of inherent noise in the system, the target location may not always have the highest activation in the activation map. Thus, according to theories of guidance, search efficiency is a function of activation in the activation map at the target location relative to the nontarget locations. Search is easy when the target provides a strong guidance signal relative to the weak spurious guidance signals by distractors, and it is difficult when the guidance signal by the target is comparable to that of the nontargets. For the search for emotional faces this means that if, for example, search for an angry target is more efficient than search for a happy target (as, for instance in Horstmann & Bauland, 2006), this indicates that the angry face guides attention to its position better than the happy face.

This guidance centered approach is highly attractive, as it allows a straightforward interpretation of search efficiency differences in terms of basic (attention guiding) features (may these be affective or perceptual; see Batty, Cave, & Pauli, 2005; S. I. Becker, Horstmann, & Remington, 2011; Horstmann, 2007, 2009; Horstmann et al., 2006, 2012; Horstmann, Becker, Bergmann, & Burghaus, 2010). Surprisingly little work, however, has been directed to alternative accounts of search efficiency, and in particular to the time spent on a stimulus (or group of stimuli) during search, which is referred to here as *dwelling* (Horstmann, Becker, & Ernst 2017; Horstmann, Herwig, & Becker, 2016). Wolfe and Horowitz (2017) also recently warned that search results are no unambiguous measure of guidance because the same search efficiency difference may result from differential guidance by the target, or from differences in the time it takes to reject distractors (i.e., in the actual search phase, when numerous items are checked).

Some insightful data about dwelling were gained from eye-tracking studies, which measured the duration of gaze lingering on a stimulus (dwell time). Some older studies already found differences in dwell time (e.g., Gould, 1967; Hooge & Erkelens, 1998; but see Zelinsky & Sheinberg, 1997), and recently, a number of studies revisited dwelling and found systematic relations between search efficiency and dwell time (S. I. Becker, 2011; Horstmann et al., 2016; Horstmann, Becker, & Ernst, 2017). In particular, Horstmann et al. (2016, 2017) showed that target–distractor similarity—probably the most important single influence on search efficiency—determined not only search efficiency but also dwell times, which (as revealed by a regression analysis) explained also considerable amounts of the variance in search efficiency. Importantly, dwell times were just as, or even more, important as a predictor of search efficiency as other indicators of guidance (such as the number of fixations on the distractors in present trials before the target).

If search efficiency is not only a function of guidance afforded by the target, but possibly also by the duration of selective processing of distractors, it is not at all clear how differences in search efficiency for emotional targets should be accounted for. These differences may mean that a particular emotional target (e.g., a happy face among neutral distractors) guides attention better than a different emotional target (e.g., an angry face among the neutral distractors), or that with a happy face target, the rejection of neutral face distractors is faster (less time consuming) than with an angry face target. Horstmann et al. (2012), Horstmann et al. (2006), and S. I. Becker et al. (2011) argued for this latter possibility in the context of emotional expression search, mainly based on the observation that better search for happy than angry faces was not only observed in present trials, but also in absent trials. Obviously, because no target is among the stimuli in an absent trial, better guidance by the target cannot be used as an explanation. The commonality between target present and absent trials, however, is the processing of the distractors. It is therefore likely that characteristics of the distractors rather than characteristics of the targets are driving the efficiency effect.

The central question in the present study is thus the following: Given that different emotional targets are presented in a visual search task that are known to reveal differences in search efficiency (as determined by the slope of the function relating reaction time (RT) to set size, Horstmann et al., 2012), how is search performance determined by variables reflecting target guidance versus distractor rejection? On the basis of Horstmann et al. (2016, 2017), we focus on three variables that each could explain search efficiency: skipping, dwelling, and revisiting. In contrast to Horstmann et al., however, here we test the classical constellation, that is, angry versus happy faces among neutral faces (cf. S. I. Becker et al., 2011). Two more narrow questions are examined. First, does the emotion factor have an impact on skipping, dwelling, and revisiting? Second, how much do skipping, dwelling, and revisiting contribute to search performance?

Skipping is the variable that guidance centered models use to account for overall search speed. With a target that strongly guides attention, few items are selected for time-consuming postattentional processing, and many items are therefore skipped. With a target that only weakly guides attention, many items in the display have to be checked before the target is finally found. In absent trials, participants adapt to the ease with which a target is found (Chun & Wolfe, 1996; Wolfe, 1998). Therefore, when a strongly guiding target is looked for and the target has not been located after selecting the best candidates, it is rather safe to conclude that the target is not in the display, and to skip the remaining stimuli. On the other hand, when a poorly guiding target is searched for, all distractors have to be checked before a "target absent" decision is made (or otherwise, accuracy is strongly jeopardized). In accordance with a guidance account, Reynolds et al. (2009) found the response time pattern in a search for positive and negative faces mirrored in the number of fixations until the target was found.

Dwelling is the variable which is assumed to account for search speed in distractor rejection efficiency accounts (e.g., S. I. Becker et al., 2011; Horstmann et al., 2006, 2012, 2016, 2017). If targets and distractors are similar to each other (e.g., Horstmann et al., 2016, 2017), or if a stimulus is difficult to perceive because of perceptual degradation (e.g., S. I. Becker, 2011; Gould, 1967; Hooge & Erkelens, 1998), categorization of stimuli as target versus distractor will be more time consuming. This factor is applicable likewise for target present and absent trials, and does not need separate mechanisms, in contrast to the guidance centered account.

Revisiting finally refers to the fact that stimuli may be selected more often than once. Selective processing is arguably the most time-consuming operation during visual search; therefore, revisiting stimuli is potentially harmful for search efficiency. Revising can have several underlying causes. For example, revisiting may be an effect of searching too fast. There is strong evidence from eye tracking that the categorization of a stimulus (as target or distractor) is not finished when the eyes move to the next stimulus, and that categorization continues during that time (e.g., Hooge & Erkelens, 1998; Remington, Lewis, & Wu, 2006). As a consequence, so called return-saccades are frequently observed, where the target is fixated, then—obviously because it was not immediately recognized—a further distractor is fixated, until finally, the eyes move back to the target. The common interpretation of this pattern is that the new fixation and the saccadic eye movement have been programmed in parallel to the categorization process, and that the saccadic eye movement preparation has reached its point-of-no-return when the target was finally recognized. Revisiting a stimulus is extremely costly, in particular when revisiting occurs in conjunction with an eye movement, where a single fixation lasts about 200–250 ms. Revisiting may also be the consequence of limited memory for already visited locations. For example, Hulleman and Olivers (2017) assume that the corresponding memory limit is about 4 items. This means that when more than 4 items are in the display, and when the display is unordered such that a systematic scanning strategy cannot be easily implemented, rescanning of items will occasionally happen.

All these dependent variables were derived from eye-tracking raw data. Eye tracking was used because it allowed the most direct measurement of the variables of interest, opposed to, for instance, the RT measure of classical visual search studies. In particular, search slope measures derived from RT lump together guidance and dwelling and are thus not adequate to examine the present research question. While not an exhaustive measure of attention (e.g., possible covert shifts of attention are, by definition, not registered), eye movements provide a spatially and temporally detailed measure of attentional deployment. Importantly, with eye tracking, there is no need to present different set sizes (i.e., a different number of distractors stimuli over trials) in order to evaluate how many distractors are visited before the target—zero in efficient search, many in inefficient search—because this datum can be directly retrieved from gaze behavior.

We expect a happy face advantage (faster RTs in search for happy vs. angry faces among neutral faces), as is usually observed with the NimStim stimulus set (Tottenham et al., 2009), and has been found by Horstmann et al. (2012), who tested a subset of the experimental stimuli in behavioral a visual search task with set sizes of 2, 4, and 9. When visible teeth are controlled for, happy faces were searched for more efficiently than angry faces, that is, the slope of the function relating RT to set size was shallower for happy face targets than for angry face targets. Theoretical predictions are as follows. On a purely guidance-based account where the emotion effect is due to differential guidance only, we expect an emotion effect on skipping but not on dwelling or revisiting. This prediction is based on the assumption that guidance drives search efficiency exclusively, and that the time used for each distractor rejection is fixed to a constant value (e.g., Chun & Wolfe, 1996; Zelinsky, 2008). Conversely, on a distractor-rejection account, we expect emotion to affect dwelling in particular (and possibly revisiting), but not necessarily on skipping. This is based on the assumption that search efficiency differences are due to differences in the duration of postattentional distractor rejection in the absence of guidance.

Of particular interest for our analyses are target absent trials. With respect to guidance, target selection latencies can be compared to the average selection latency in absent trials. If the target is selected earlier than a random absent-trial distractor, this would be convincing evidence for guidance. With respect to distractor rejection, we should be able to observe differences in distractor rejection duration in both target present and target absent trials. In fact, as there is no target in an absent trial (by definition), distractor rejection should be observed most purely in an absent trial. A complementing analysis, where RT is statistically regressed on skipping, dwelling, and revisiting, tests how much these variables contribute to variations in search time.

Our study conformed to all but one of the recommendations by D. V. Becker et al. (2011). These authors comprehensively discussed theoretical and methodical issues and gave five recommendations: (1) Set size must be varied; (2) the content of the distractor crowds must be held constant; (3) participants are searching consciously for a particular type of expression; (4) perceptual confounds should be avoided; and (5) distractors should be heterogeneous. In our study, the distractors were all neutral faces (recommendation 2), and participants searched for a happy or an angry target in separate blocks (recommendation 3). We avoided perceptual confounds by presenting closed lipped facial expressions throughout (recommendation 4), which has been shown to be a possible confound (Horstmann et al., 2012, 2016, 2017), and by presenting heterogeneous displays composed of 10 individuals, half of whom were men and half women (recommendation 5). We did not vary set size (recommendation 1), because the set size variation is used to extract rate of processing (items per time, or time per item) from RT data. Here, however, we used eye-tracking, which enables us to detail rate of processing from gaze behavior. Note that Horstmann et al. (2012) used a subset of the present stimuli in an RT study that varied set size, showing differences in RT/set size slopes in search for happy versus angry faces.

Methods

Participants

Seventeen students participated in the study. They received €4 for their 30 min participation. Two of them were excluded from the sample because performance was near chance level in in the angry target present condition, leaving seven women and eight men in the analysis, with a mean age of 27 (SD = 3.7) years. Sample size (N = 15) was planned based on Horstmann et al. (2017), who used the same methods, and informed by Horstmann et al. (2016), who used very similar analysis technics. In both of these studies, sample size was N = 12. Note that our second analysis concerns two linear multilevel regressions with trial as the unit of analysis. The number of trials per participant was 80, such that the linear multilevel regression is based on 600 target absent trials and 600 target present trials. Even though the number of finally analyzed observations would be somewhat lower because trials with errors (wrong key press) and trials with extreme values on dwelling and search times are not included in the analysis, we expect more than 500 observations in the analysis, which should be more than sufficient to obtain reliable data. The research received approval by the Committee for Ethics at the Department of Psychology, Bielefeld University.

Stimuli

Stimuli were partially the same as in Horstmann et al. (2016, 2017). They were drawn from the NimStim stimulus set (Tottenham et al., 2009). Five female models (01, 02, 03, 07, and 08) and five male models (20, 21, 22, 23, and 24) provided a neutral face, a happy face, and an angry face. All stimuli displayed a closed mouth. Thus, a total of 30 pictures of faces were used. Each color picture subtended 77 × 99 pixels (2.1° × 2.8°) and was coded as a bitmap with a color depth of 24 bits (see Figure 1 for an example of the three expressions that were used from each model).

Search displays consisted of 10 pictures presented in 10 randomly selected cells, excluding the center position, of a 3 × 5 matrix with a horizontal spacing of 100 pixels (2.8°) and a vertical spacing of 130 pixels (3.6°). The center position, where also the fixation stimulus appeared, was never used for a stimulus. Pictures were presented centered on the cells of the matrix, with an additional random jitter of 5 ± 5 pixels horizontally and vertically.

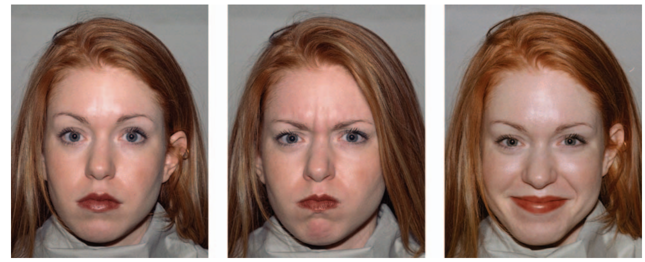

Figure 1. Examples of the neutral face (left), the similar target (center), and the dissimilar target (right). Faces were drawn from the NimStim stimulus set (Tottenham et al., 2009). See the online article for the color version of this figure.

Apparatus

Stimuli were presented on a 19-in. display CRT monitor (100-Hz refresh rate, resolution 1,024 × 768 pixels) at a distance of 71 cm. A video-based tower-mounted eye tracker (EyeLink 1000, SR Research, Ontario, Canada) with a sampling rate of 1,000 Hz was used for the recording of eye movements. The participants' head was stabilized by a chin and forehead rest, and in all participants, the right eye was monitored. Before the experiment commenced, the eye tracker was calibrated using a 9-point calibration. The experiment was programmed using Experiment Builder 1.10.1630 (SR Research, Ontario, Canada), and eye tracking data were preprocessed using Data Viewer 2.3.22 (SR Research, Ontario, Canada).

Design

The experiment comprised 5 blocks, which differed only in the target category, if present. The distractor category remained the same for all blocks, being an emotionally neutral face. Each block contained 20 trials, 10 of which were target present trials, and 10 were target absent trials. Blocks with similar targets alternated with blocks with dissimilar targets. Half of the participants started with an angry target block. This first block was considered as practice and omitted from the analysis.

For each trial, 1 of the 10 models (facial identities) was selected. If the trial was designated as a target present trial, this model displayed an emotional face; if the trial was designated as a target absent trial, this model showed the same neutral face as the other distractors. The remaining nine stimulus positions were filled randomly with the remaining nine neutral faces. Each model was presented once in a block as a target. Target absent trials consisted of the same collection of neutral faces throughout all blocks.

Procedure

Each trial started with a fixation control, which was terminated with a key press (with the left hand) that also initiated the presentation of the search display. The task was to indicate with a key press (index or middle finger of the right hand) whether or not one of the 10 possible targets was presented in a trial. The search display was shown until the key press response was registered. Prior to each block, the 10 possible targets were displayed side by side on the monitor for ad lib inspection, with the aim of providing an overview of their appearances to the participant.

Eye Tracking Data Preprocessing

Raw eye position data were parsed by the eye tracker software's standard experimental setting, which uses a speed threshold (30°/s) and an acceleration threshold (8,000°/s^2) to detect saccades. Areas of interest were defined that enclosed the face pictures almost exactly (i.e., they were 1–2 pixels larger than the picture).

From these preprocessed data, four variables were derived for analysis. Each stimulus was classified as being fixated within a given trial or not. If a stimulus was fixated, first visit dwell time was assessed, which is the sum of the fixation durations over the first continuous series of fixations on that stimulus. Also, the latency of the fixation relative to the onset of the search display was retrieved. This measure is conceptually similar to a manual RT, with the difference that for n fixations in a given trials, n latencies were registered. Furthermore, we assess whether a stimulus is visited only once, or whether it is revisited, that is, visited a second time.

The basic units of analysis, however, are statistics for each trial. *Skipping* is the proportion of stimuli that have not been fixated in a trial. Skipping is the variable that drives trial RT, as assumed by guidance-based theories of visual search. *Dwelling* is the average (first visit) dwell time (i.e. the sum of the fixation durations during a continuous run of fixations on a stimulus) for the stimuli visited in a trial. We predict dwelling to be a substantial influence on RT, whereas guidance-based theories treat dwelling as a constant. In addition to dwelling and skipping, we also assessed the proportion of stimuli that had been revisited, because *Revisiting* is a third possible source of variance in manual RT. Finally, manual RT is measured, which is the time between display onset and the pressing of the correct answer key.

Results

Error Rates

Mean proportions correct for the conditions angry target absent, happy target absent, angry target present, and happy target present were .97, .99, .88, .91, respectively. An ANOVA with the variables target emotion (angry vs. happy) and target presence (present vs. absent) revealed a significant main effect for presence, $F(1, 14) = 43.64$, $p < .001$, $\eta^2_G = .41$, and emotion, $F(1, 14) = 8.21$, $p = .012$, $\eta^2_G = .09$. More errors were made in present trials, reflecting the fact that a nontarget was rarely mistaken for a target, but that sometimes a target is not identified; and more errors were made in blocks with the angry target, indicating that the angry target was more difficult than the happy target.

Reaction Times

Trials with errors in the search task, where RTs were implausibly short (<300 ms) or exceeded the .99th percentile of the RT distribution (7405 ms) were removed from all following analyses. Figure 2 shows the main results. An ANOVA computed over mean RTs with the variables emotion (angry vs. happy) and target presence (present vs. absent) revealed significant main effects for both variables (presence: $F(1, 14) = 185.60$, $p < .001$, $\eta^2_G = .67$; emotion: $F(1, 14) = 13.43$, $p = .003$, $\eta^2_G = .11$;). Target present RTs were shorter than target absent RTs (2163 ms vs. 3625 ms), and happy target blocks rendered lower RTs than angry target blocks (2717 ms vs. 3072 ms). As error rates and RTs are in the same direction (higher error rates where RTs are high), we conclude that the data are not contaminated by a speed–accuracy trade-off. Taken together, the results from error rates and RTs indicate that we have a search advantage for the happy face over the angry face.

Fixation Count

The total number of fixations was analyzed by means of ANOVA with the variables emotion (angry vs. happy) and target

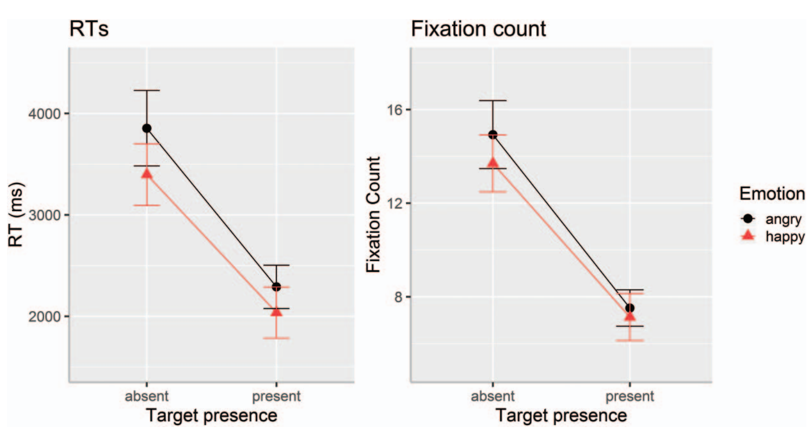

Figure 2. Mean RTs (left) and mean number of fixations (right) for trials with high and low target-distractor similarity, in target absent and present trials, respectively. Error bars are 95% confidence intervals for the means. See the online article for the color version of this figure.

presence (present vs. absent). The main effect for target presence was significant, $F(1, 14) = 216.21$, $p < .001$, $\eta^2_G = .75$, reflecting more fixations in absent than present trials (14.3 vs. 7.3). The main effect for emotion just failed conventional significance levels, $F(1, 14) = 4.55$, $p = .051$, $\eta^2_G = .04$. The mean number of fixations in search for an angry target tended to be larger than for a happy target (11.2 vs. 10.4). The interaction was not significant, $F(1, 14) = 2.97$, $p = .11$, $\eta^2_G = .01$.

Dwell Times

Fixation dwell times that were either very short (less than 40 ms, 8 instances) or exceeded the 99th percentile of the distribution (621 ms, 84 instances) were excluded from the analyses of mean dwell times. Figure 3a shows the main data. An ANOVA of the dwell times with the variables emotion (angry vs. happy) and stimulus type (distractor in absent trial vs. distractor in present trial vs. target in present trial) rendered significant main effects for emotion, $F(1, 14) = 7.91$, $p = .014$, $\eta^2_G = .05$, and stimulus type, $F(2, 28) = 14.23$, $p = .001$, $\eta^2_G = .31$ (interaction: $F < 1$). The dwell time difference for emotion was 18 ms, that is, stimuli were looked at on average 18 ms longer in the angry than the happy target block. The main effect of stimulus type was due to 22 ms longer dwell times on distractors in absent than present trials, $t(14) = 7.10$, $p < .001$, and 52 ms longer dwell times on the target than on distractors in present trials, $t(14) = 4.41$, $p < .001$.

Proportion of Fixated and Skipped Stimuli

Figure 3b provides an overview of the proportion of fixated versus skipped stimuli. As one of our variables of interest is skipping, we will present the data accordingly as the proportion of skipped stimuli.

An ANOVA of skipping rates with the variables emotion (angry vs. happy), and stimulus type (distractor in absent trial vs. distractor in present trial vs. target in present trial) rendered a significant main effect for stimulus type only, $F(2, 28) = 129.98$, $p < .001$, $\eta^2_G = .77$ (emotion: $F(1, 14) = 2.66$, $p = .12$; interaction: $F(2, 28) < 1$). Less distractors were skipped in absent than in present trials, $t(14) = 25.54$, $p < .001$, and the target was skipped less often than a distractor in a present trial, $t(14) = 8.96$, $p < .001$.

Revisiting

Figure 3c provides an overview of the proportions of revisits on distractors in absent trials, distractors in present trials, and targets in target present trials. An ANOVA of revisiting rates with the variables emotion (angry vs. happy) and stimulus type (distractor in absent trial vs. distractor in present trial vs. target in present trial) rendered significant main effects for emotion, $F(1, 14) = 6.74$, $p = .021$, $\eta^2_G = .04$, and stimulus type, $F(2, 28) = 19.41$, $p < .001$, $\eta^2_G = .33$ (interaction: $F(2, 28) = 2.56$, $p = .12$). Stimuli are revisited more often in blocks with angry than happy targets (.17 vs. .13). The main effect of stimulus type was due more revising on distractors in absent than in present trials (.22 vs. .06), $t(14) = 6.62$, $p < .001$. The revisiting rate was not significantly different between distractors in absent trials and the target in the present trial (.22 vs. .17), $t(14) = 1.94$, $p = .07$.

Selection Latencies

Figure 3d shows the selection latencies. An ANOVA of the latencies with the variables emotion (angry vs. happy) and stimulus type (distractor in absent trial vs. distractor in present trial vs. target in present trial) rendered significant main effects for stimulus type only, $F(2, 28) = 80.15$, $p < .001$, $\eta^2_G = .61$ (main effect emotion: $F(1, 14) = 3.05$, $p = .10$; interaction: $F < 1$). The only interesting comparison for this variable is between the selection latency for the target and the average selection latency for a distractor in an absent trial, because it could be argued that if the target is selected earlier than a random distractor from a target absent trial, this indicates guidance. This comparison, however, was not significant, $t(14) = 1.68$, $p = .11$, indicating that the target was found in an unguided and exhaustive search. The two remaining comparisons were highly significant, $ts > 9.61$, $ps < .001$, indicating that the average selection latency for a distractor in a target trial was comparably low.

Focusing again on a possible guidance effect, we additionally analyzed the advantage of the target in the target present trial over the same facial identity in a target absent trial. Recall that for each trial, one of the faces was selected as the potential target, which was then shown as an emotional face if the trial was a target present trial and as a neutral face if the trial was a target absent

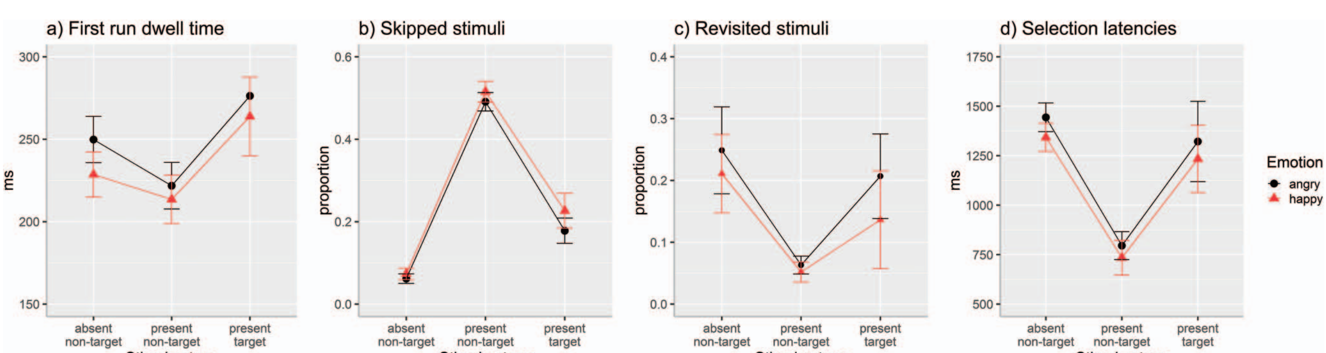

Figure 3. Mean dwell times, proportions of skipped stimuli, proportions of revisited stimuli and fixation latencies for blocks with high and low target-distractor similarity in target and present trials. Error bars are 95% confidence intervals for the means. See the online article for the color version of this figure.

trial. Mean RTs were analyzed by ANOVA with the variables emotion (happy vs. angry) and presence (present vs. absent). However, neither emotion, $F(1, 14) = 3.40$, $p = .086$, presence, $F(1, 14) = 2.74$, $p = .120$, nor their interaction, $F(1, 14) = 1.18$, $p = .295$, were significant. Thus, our analysis did not show better guidance by the happy face than by the angry face, which might be expected based on the RTs. In fact, there was only very weak evidence for guidance at all, if the marginally nonsignificant effect of presence is taken as an indication.

Specificity of the Effect of Emotion on Dwelling

Is the effect of emotion category on dwelling on distractors specific or does it reflect a general change in performance speed? We examined the latency of the very first saccade in a trial. Recall that participants gaze at a fixation marker at the beginning of a trial and that no target or distractor was ever presented at that position. Thus, if the effects of emotion category on dwelling reflect a general reduction of performance speed, we should also find differences for the duration of the starting fixation. If, in contrast, the effects reflect differences in stimulus processing, emotion should have no effect on the duration of this starting fixation because the fixation was not a stimulus. The average duration of this first fixation was 168 ms. Mean latencies of the first saccade (based on 1125 observations) did show a performance slowing of only 3 ms, which was not significant when tested by ANOVA (present: $F(1, 14) = 3.69$, $p = .075$; emotion: $F(1, 14) = 2.92$, $p = .11$; interaction: $F < 1$).

Contributions of Dwelling, Skipping, and Rescanning to Search Times

Search times are basically the sum of fixation durations, or put otherwise, the product of the number of fixations and their mean duration. This implies, however, that it is unclear to what degree search time differences, in our case between searches for angry versus happy targets, depend on differences in the number of fixations or the duration of fixations. The ANOVAs discussed thus far have shown that emotion has a similar impact on RT as on dwelling, but this could be mere coincidence. What is missing is an indication that dwelling actually affects RTs.

In the following we will present a correlational analysis with the aim to detail the shared variance among dwelling, skipping, and revisiting, on the one hand, and RT, on the other hand. The unit of analysis is the trial. Thus, we examine the degree in which trial search time is determined by skipping rate on a trial (i.e., the proportion of stimuli that is not looked at on a trial), rescanning rate on that trial (i.e., proportion of stimuli on a trial that are looked at more than one time), and average dwelling time in that trial (i.e., the average duration of dwelling on stimuli on a trial). The bivariate correlations among RT, revisiting rate (revisiting), skipping rate (skipping), and dwell time (dwelling) on the level of trials separately for target absent and present trials are given in Table 1. As Table 1 reveals, the first order correlations of dwelling, skipping, and revisiting with RT are very high. Table 1 also includes the correlations of RT, dwelling, skipping, and revising with emotion. Note that these correspond to the main effects of emotion in the ANOVAs.

Figure 4 presents the corresponding scatterplots. Each point is a trial. Whether a given trial was from an angry or a happy target block is color-shape coded (red circles and blue diamonds, respectively). There are clear linear relations between the predictor variables dwelling, skipping, and revisiting, respectively, and the dependent variable RT. Note that the linear relationships are roughly the same for blocks with angry and happy target blocks, as red circles and blue diamonds align without apparent discontinuity on a single linear function.

The first order correlations also reveal shared variance between the predictor variables. For instance, skipping and revisiting show a positive correlation, which complicates the interpretation of the correlations of these variables with RT, respectively. To obtain the unique effects of the predictors on RT, RT was regressed on dwelling, skipping, revisiting, and emotion.

Linear multilevel regression with random intercepts for each of the subjects and fixed slopes were used to model between-subjects variation. Metrical variables were z-transformed prior to regression, to allow for direct comparisons between regression coefficients. For emotion, angry target blocks were dummy-coded as zero and happy target blocks were coded as one. We included emotion to test whether emotion may influence RT independently from simple effects of average dwelling, skipping, and revisiting. We have already seen from the ANOVAs and from the correlations in Table 1 that emotion has an impact on dwelling in target absent trials and on skipping in target present trials. As our analysis is based on a considerable number of observations, and as t-distributions converge with the standard normal distribution with a high number of observations, we interpret empirical $t > |1.96|$ as significant.

Table 1
Correlation Matrix for the Variables Similarity, RT, Skipping, Dwelling, and Revisiting in Target Absent and Target Present Trials

Variable	Emotion	RT	Skipping	Revisiting
Absent				
RT	−.23			
Skipping	.07	−.52		
Revisiting	−.09	.77	−.38	
Dwelling	−.27	.58	−.05	.16
Present				
RT	−.13			
Skipping	−.04	−.87		
Revisiting	−.08	.63	−.49	
Dwelling	−.09	.45	−.27	.12

Note. Correlations were calculated on trial measure. Coefficients $\geq |.09|$ are significantly different from zero, $p < .05$.

Target Absent Trials

The number of observations for absent trials was 581. Collinearity among the predictor variables was low, as indicated by the *variance inflation factor* (*VIF*), with all $1/VIF > .83$. All predictors revealed significant effects (see Table 2, upper panel), with revisiting (b = .58) and dwelling (b = .45) having a somewhat stronger unique effect on trial RTs than skipping (b = −.26) and emotion (b = −.09). Marginal R^2 was .87 (Nakagawa & Schielzeth, 2013).

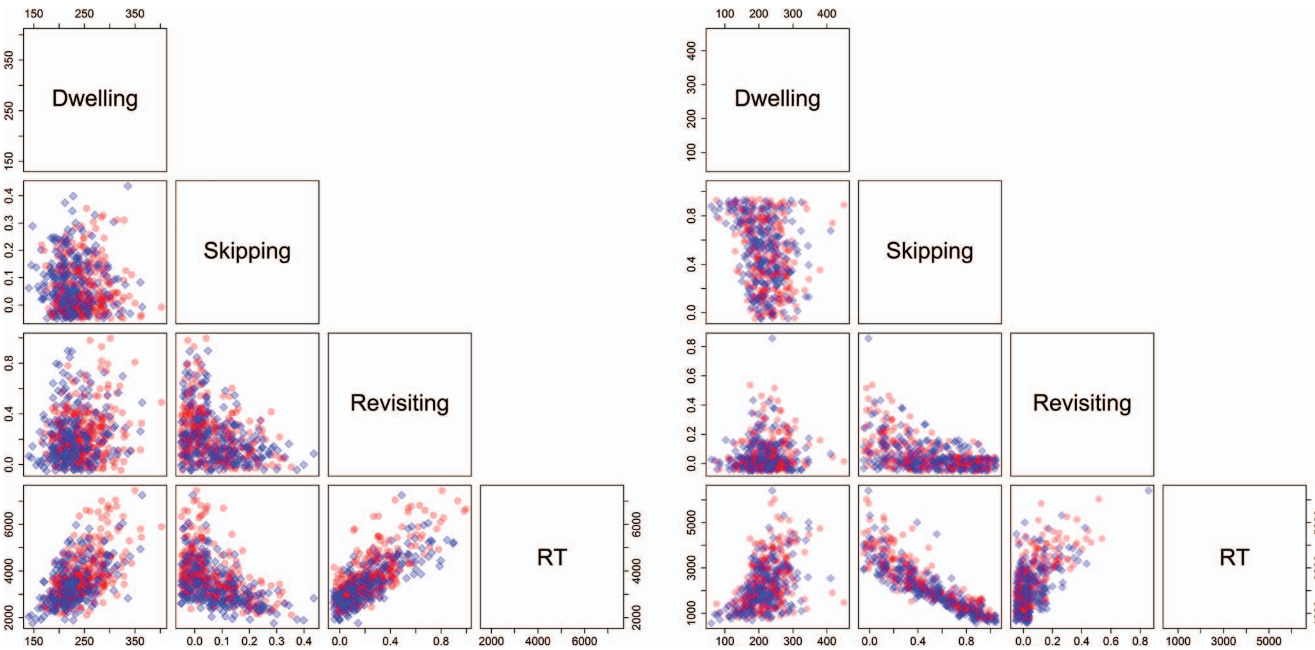

Figure 4. Bivariate relationship between trial search times (RT), revisiting rates (Revisiting), skipping rates (Skipping), and dwell times (Dwelling), for distractors in target absent trials (left panel) and target present trials (right panel) per participant. Target-dissimilar and target-similar distractors are presented as red circles or blue diamonds respectively. See the online article for the color version of this figure.

Target Present Trials

Only distractor fixations are analyzed, as in the previous analysis. The total number of analyzed target present trials was 502. Indications of collinearity were low, $1/VIF > .75$. All slopes were significantly different from zero (Table 2, lower panel). Skipping (b = −.69) dominated in this analysis, which is of no surprise as in target present trials, the target is found after a variable number of inspected distractors. Thus, skipping is expected to be the most important determinant of RT in target present trials because search terminates after the target has been found. Importantly, dwelling (b = .20), and revisiting (b = .26), independently contributed to RT. Marginal R^2 was .86.

Table 2
Linear Multilevel Regression of Target Absent and Present Trial Reaction Times on Dwelling, Skipping, Revisiting, and Similarity as Fixed Effects and Random Intercepts for Participants

Variable	b	*SE*(*b*)	t
Absent			
Intercept	.05	.03	1.45
Dwelling	.45	.02	25.62
Skipping	−.26	.02	−15.46
Revisiting	.58	.02	33.86
Emotion	−.09	.03	−2.80
Present			
Intercept	.06	.04	1.26
Dwelling	.20	.02	11.98
Skipping	−.69	.02	−36.80
Revisiting	.26	.02	15.07
Emotion	−.11	.03	−3.81

Note. *b* = regression coefficient; *SE* = standard error of regression coefficient. Models allowed for random intercepts between subjects; full maximum likelihood was used as estimation method; with the exception of emotion, all metrical variables were *z*-transformed prior to analyses; for emotion, "angry" was coded as zero and "happy" as one; and all coefficients except the intercept are interpreted as significant by *t*-values exceeding ±1.96.

Discussion

When participants searched for a happy or an angry face in a crowd of neutral distractors, they found the happy target faster than the angry target (happiness superiority effect), and were similarly faster in their decision to stop searching in an absent trial. These results are in line with previous studies that used similar stimulus materials (e.g., Horstmann et al., 2012).

The critical question in the present research is the following: Does the difference in RT reflect differential guidance by the happy versus angry target, that is, its preattentive processing? Or is emotion rather influencing other search related variables, such as dwelling or rescanning, that relate more to postselective aspects of stimulus processing? Two sets of analyses potentially answer this question: one was as set of ANOVAs, the other comprised a pair of linear regressions.

The ANOVAs analyzed the RT and eye-tracking data with respect to possible effects of emotion on average stimulus dwell time, skipping, and revisiting, to check whether these variables showed the same happiness superiority effect as found in mean RT. We found similar effects as in the mean RT on dwell time and rescanning, whereas we did not find evidence for emotion to influence skipping. Finally, we did not find indications for guidance as the target in target trials was not fixated earlier than a random distractor in absent trials. Note that we do not claim that there was no guidance in the present experiment. However, the present results strongly contradict the possibility that the emotion effect is due to guidance exclusively. Evidence is positive for dwelling, as predicted by a distractor-rejection approach, and also for rescanning, but not for guidance. The entire pattern of results suggest that the happy face target is found faster because of shorter dwelling on distractors and less frequent rescanning of already analyzed distractors, but not necessarily because of better guidance.

It might be objected that guidance is better tested when target emotion is not blocked, as in the present experiment, but when different target types (i.e., angry and happy) are presented unpredictably in the same block (e.g., Eastwood et al., 2001; Reynolds et al., 2009). We object that this procedure leaves the target template (e.g., Duncan & Humphreys, 1989) completely uncontrolled (D. V. Becker et al., 2011). The target template is the mental representation that is used during search to detect the target. With a single target per block, it is reasonable to assume that participants use a target template that best supports good performance, for each target face. It is also clear that the target templates for the happy and the angry face categories differ. It is less clear how participants solve the task of searching for two different face categories at once. They may use an intermediate target template that is able to match both categories. Then the problem arises that the intermediate template may nonetheless match one of the targets better than the other. Or participants may perform a hybrid search, where each search item has to be matched to each of the memory items (Wolfe, 2012). Then it is quite possible that no guidance effects could be found at all; at least it is usually assumed that guidance requires a unitary target template. Finally, participants could search for a perceptual singleton, which is an item that is most different from the remaining stimuli. The possibilities of intermediate target templates and hybrid search are not applicable when one target type is presented per block. Searching for a perceptual singleton would be an inferior strategy, given that each trial presented 10 individuals, both men and women, rendering all items different from one another. Actually, it is usually assumed that singleton search is only feasible with low distractor heterogeneity; if the distractors are heterogeneous, it is assumed that participants are forced to search for a particular feature or a conjunction of features (Bacon & Egeth, 1994).

Our second analysis connects two results from the ANOVA analyses, the emotion effect on RTs on the one hand, and the emotion effect on dwelling and revisiting on the other hand. It is theoretically possible that emotion influences dwelling while dwelling does not systematically influence RT. The analyses clearly show that this concern is not valid. Specifically, we examined the amount of explained variance in RT by the variables dwelling, skipping, and revisiting. For both target absent and present trials, all variables contributed to search times. In absent trials, most of the variance was explained by revisiting, followed closely by dwelling, and finally by skipping. For present trials, skipping explained most of the variance, followed by revisiting and dwelling. The results are not only relevant to our main focus on the emotion effect in visual search, these results also have implications for general models of visual search, as they show that target guidance is not the only variable needed to explain search performance but that dwelling and revisiting are additionally needed to account for visual search performance.

What we have seen so far is that faster search for happy faces does not necessarily imply stronger guidance. Note that the significant effect for skipping in the regression for target present trials is no indication of guidance. Assuming random selection of the target, the target is found in target present trials after a variable number of distractors, and each serial position within the stimulus visiting sequence has the same probability of $p = .10$. It is therefore entirely expected that in target present trials, skipping is the most important predictor of search times, because the serial position within the stimulus visiting sequence is a very strong source of variance in the search times. On the basis of distractor rejection efficiency accounts, target absent trials are much better suited to examine dwelling, skipping, and revisiting. Target present trials, in contrast, provide evidence mainly for random variation of when a distractor is found.

The present results have important implications for the interpretation of search slope differences in visual search, in emotion research and elsewhere. It has been argued, for instance, that a shallower slope for angry faces than for happy faces in visual search indicates better guidance of attention by the angry than the happy face (e.g., Eastwood et al., 2001; Frischen et al., 2008; Hansen & Hansen, 1988; Öhman et al., 2001; see also Öhman, Flykt, & Esteves, 2001). As already argued by Horstmann et al. (2006) and Horstmann et al. (2012), better guidance is not the only explanation for shallower search slopes, because the search slopes can also be explained by more or less efficient distractor rejection in a serial search (see also Wolfe & Horowitz, 2017). These studies, however, did only provide indirect evidence. The present study provides a direct proof-of-concept that more efficient search for one facial emotion category can be entirely due to distractor rejection processes rather than target guidance. Of course, this does not mean that distractor rejection, but not target guidance, explains all search slope differences in other studies. It is, however, often not possible to unambiguously interpret the results of previous studies as most of them did not report measures of distractor rejection such as dwelling and rescanning that are independent of the concept of guidance. For the future, we thus recommend the use of eye-movement measures to disentangle the effects of guidance by the target on the one hand and guidance-independent determinants of distractor rejection on the other.

Based on the reasoning of Horstmann et al. (2016, 2017), we assume that the present results are brought about by the perceptual similarity of the targets with the distractors. More precisely, we assume that the happy target is perceptually less similar to the neutral distractors than the angry target. Target-distractor similarity is probably the most important and most pervasive single factor determining search efficiency. It is assumed (cf., e.g., Duncan & Humphreys, 1989; Hulleman & Olivers, 2017; Zelinsky, 2008) that visual search depends on the comparison between a target template and a distractor or a group of distractors. The target template is a representation of the target and can be thought of as its perceptual signature. This perceptual signature for a given target may not be the same for all searches, but rather be tailored to the present search context if this context is known (cf., e.g., Zelinsky, 2008). For illustration, consider the search for a yellow rubber duck in either a bowl of yellow rubber cats or a bowl of red rubber ducks. It seems reasonable that shape is the most important signature of the yellow rubber duck in the first search environment but color in the second. During the search process, the perceptual signature of the target is searched for in the environment. With distractors sufficiently different from the target, the absence of the target in a particular region of space is easily determined, and it might be often possible to scrutinize a region in space that includes several nontargets at once (Hulleman & Olivers, 2017; Venini, Remington, Horstmann, & Becker, 2014). When target and distractors are similar, it might be necessary to reduce the inspected region to one stimulus, or even a subregion of the stimulus. Moreover, even when a single stimulus is fixated, the time of the comparison may still be a function of the similarity between target and the stimulus. That is, a decision that the present stimulus is the target versus a distractor is more difficult and thus more enduring when distractors are generally similar to the target in the task at hand.

It might be argued that the main effect of emotion on RT and on dwell time can be explained by assuming a threat-driven generic cognitive slowing (Algom, Chajut, & Lev, 2004) in blocks that involved an angry target, induced by the threatening stimulus, which was absent in blocks with the happy target. We would argue against this contention by pointing out that there is no consistent evidence that threat generally induces a cognitive slowing; actually, threat is more often assumed and found to increase processing speed (e.g., Öhman, 2005). To further explore this possibility, we analyzed the latency of the first fixation in a trial. If everything is slowed down in a block with angry targets, then the proposed effect should be found also with this first fixation. We found, however, only a (nonsignificant) 3-ms slowing when the angry rather than the happy target is searched for. To conclude, a general threat-driven slowing seems to be an insufficient explanation for the effects of emotion category on RTs and on dwell times.

We prefer an explanation of search results in terms of perceptual factors, because these factors are well known and thoroughly explored in experimental research. This is not to deny that emotional factors play a role in visual search. For instance, appraisal theories pose that negative emotions are due to an appraisal that something unwanted ("goal-inconsistent") happened, whereas positive emotions signal that something wanted ("goal-congruent") occurred (e.g., Ortony, Clore, & Collins, 1990; Roseman, 1984). Similar arguments can be made more specifically with respect to faces (Fridlund, 1994). It is therefore reasonable that negative stimuli are looked at longer than positive stimuli, and that there are biases to look preferentially for negative stimuli, in particular in unsecure or threatening environments. Facial expressions of emotion, however, are probably not the ideal stimulus for detailing whether stimulus valence directly affects the grabbing of attention (guidance) or the binding of attention (dwelling), because affective and perceptual features are intrinsically confounded. The best approach to disentangle these two factors seems to be to actively manipulate stimulus valence in an experimental setting, for example, using classical conditioning (e.g., Batty et al., 2005). A second approach might be to use stimuli varying in valence from many different categories such that perceptual attributes are unlikely to be confounded with valence. It is up to future research to examine whether stimulus valence may in fact affect visual search.

Conclusion

It is tempting to interpret differences in visual search efficiency to reflect differences in guidance. As search time is roughly the product of the number of fixations and their mean duration, more efficient search may reflect either fewer fixations (indicating guidance) or shorter fixations (indicating more efficient distractor rejection). Here we have shown that faster search for one emotion category can occur in the absence of better guidance, in particular due to shorter dwelling on the stimuli.

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