COGNITION AND EMOTION
2009, 23 (2), 355–379

Psychology Press
Taylor & Francis Group

# Visual search for schematic affective faces: Stability and variability of search slopes with different instances

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The threat-advantage hypothesis that threatening or negative faces can be discriminated preattentively has often been tested in the visual search paradigm with schematic stimuli. The results have been heterogeneous, suggesting that the choice of particular stimuli have profound effects on search efficiency. Because this conclusion is hampered by differences in experimental procedure, I selected examples from past literature and presented replicas of stimulus pairs (schematic positive and negative faces) in a within-participants design. Although there was a consistent advantage for angry-face targets, search efficiency varied between 8 and 35 ms/item, yielding no clear evidence for the threat-advantage hypothesis. Furthermore, search efficiency for negative- and positive-face targets was highly correlated over stimulus pairs, which implies that whatever complicates the search for the negative face of a pair also complicates the search for the positive face. This results pattern argues against the hypothesised preattentive detector.

A number of emotion theorists have proposed that affective stimulus characteristics such as negative valence or threat can be processed preattentively by specialised feature detectors (e.g., Mogg & Bradley, 1999; Öhman, 1999; but see Matthews & Wells, 1999). Hard-wired threat detectors that operate independent of selective attention would be adaptive from an evolutionary psychology view. Responding quickly and without conscious preponderance to potentially damaging stimuli is often advantageous in natural environments (see also LeDoux, 1998) and would thus provide the selective pressure for an evolution of specialised information processing capabilities during the human phylogeny. Because quick responses to beneficial stimuli do not provide a balanced selective pressure, preattentive

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I am indebted to Nadine Hübner, Nadine Potthast, and Nadine von Rothkirch, for collecting the data, Lily Silny for assistance in manuscript preparation, and to Stefanie Becker, Michael Niepel, Murray White, and two anonymous reviewers, for their helpful comments on an earlier version of the manuscript.


www.psypress.com/cogemotion DOI: 10.1080/02699930801976523

detectors are assumed to exist only to negatively valenced and not to positively valenced information. Following this line of reasoning, the more specific hypothesis that preattentive processing is limited to negative stimuli has been put forward.

The standard diagnostic for preattentive processing is the visual search paradigm. It tests whether a stimulus can be selected for further processing on the basis of information that is not within the current focus of visuo-spatial attention. The task is to find a target among distractors (e.g., Treisman & Gelade, 1980; Wolfe, 1998, 2001). If a target feature that is preattentively available is searched for, it can be found *efficiently*. Efficient search is a label used to denote that detection latency is independent of *set size*, which is the number of stimuli presented in a given trial. For example, if an angry face is found equally fast among few as well as among many happy faces, search is efficient by definition and preattentive availability of some feature of the angry face is assumed. However, search may be inefficient, which means that detection latency is positively related to set size. This search pattern indicates that target detection is the result of the serial deployment of focal attention on the stimuli in succession until the target is detected.[1] Search efficiency is precisely defined as the slope $b$ of the linear equation $y = bx + a$ that relates finding latency ($y$) to set size ($x$). Slopes of near 0 ms per item are labelled as very efficient, around 5–10 ms as quite efficient, around 20–30 ms as inefficient, and over 30 ms as very inefficient (Wolfe, 1998).

In theory (e.g., Treisman & Gelade, 1980, Wolfe, 1994), efficient search is possible if a single perceptual feature for which a preattentive detector exists is present in the target and absent in the distractors (e.g., a /-target among ?-distractors). In contrast, non-efficient search results if target and distractors share basic perceptual features (e.g., horizontal and vertical lines in the letters H and U), whose specific conjunction discriminates the target from the distractors. A specific conjunction of basic features (e.g., lines forming an H), in turn, normally requires attention to be discriminated from other conjunctions (e.g., lines forming a U). While it was initially thought that feature search is always efficient and that conjunction search is always inefficient (e.g., Treisman & Souther, 1985), it turned out that some conjunction searches are also very efficient. Thus, efficient search is a necessary, but not sufficient, criterion for preattentive processing (Wolfe & Horowitz, 2005).

Hypothesised preattentive detectors have often been tested with a particular visual search task that examines search asymmetries (e.g., Treisman & Gormican, 1988; Treisman & Souther, 1985; Wolfe, 2001).

[1] Note that throughout the article, I refer to covert shifts of attention that need not necessarily coincide with overt shifts, i.e., eye movements (cf. Posner, Synder, & Davidson, 1980).

This design compares performance in two conditions where the target of one condition serves as the distractor in the second condition and vice versa. For example, participants may search for an angry-face target among friendly-face distractors in some trials and for a friendly-face target among angry-face distractors in other trials. A classical search asymmetry is revealed if pop-out search is found in one condition and serial search in the other, for example, if the search for an angry among happy faces is efficient, whereas the search for a happy among angry faces is inefficient. Treisman and Souther (1985); see also Treisman & Gormican, 1988) advocated search asymmetry as an important diagnostic for a preattentively available basic feature (see also, Wolfe & Horowitz, 2005), which is then present in the pop-out stimulus (e.g., the angry face) but less so in the serial search stimulus (e.g., a happy face).



## Search asymmetries with emotional faces

A number of studies used the search asymmetry design to test whether facial valence is preattentively available. The basic idea behind these studies was that a threatening face shows high quantities of facial threat whereas a friendly face shows zero quantities of facial threat. Thus, according to the logic of the search asymmetry design (cf. Wolfe, 2001), the preattentive threat-detector hypothesis predicts pop-out of a threatening target in a friendly crowd but no pop-out for a friendly face in a threatening crowd.

Hansen and Hansen (1988) were the first who reported a classical search asymmetry with pop-out for an angry-face target among happy-face distractors and steep search slopes for a happy-face target among angry-face distractors. Later studies, however, revealed that the stimuli presented in this study, which were obtained by converting greyscale photos into high-contrast black-and-white images, incidentally carried confounds, and that these confounds, rather than the depicted emotional expressions, probably caused the search asymmetry (Purcell, Stewart, & Skov, 1996; see also Hansen & Hansen, 1994).

Many subsequent experiments (e.g., Eastwood, Smilek, & Merikle, 2001; Fenske & Eastwood, 2003; Fox et al., 2000; Horstmann, 2007; Horstmann, Scharlau, & Ansorge, 2006b; Nothdurft, 1993; Öhman, Lundqvist, & Esteves, 2001; Tipples, Young, & Atkinson, 2002; White, 1995) have used schematic stimuli (rather than naturalistic stimuli) that allow for a much better control of perceptual differences between positive, negative, and sometimes neutral faces. Most researchers simply wanted to circumvent the possible problems that surround the presentation of photos, but some authors even regarded schematic faces as "superoptimal" stimuli in the ethological sense where simplified or exaggerated stimuli excite inborn releaser mechanisms better than their real counterparts (e.g., Öhman et al., 2001; but see Horstmann & Bauland, 2006; Horstmann, Borgstedt, & Heumann, 2006a). Irrespective of the pros and cons for schematic versus realistic stimuli, it must be stated that studies with schematic stimuli are centrepieces of the evidence relevant to the threat-advantage hypothesis. Thus, the present study deals with schematic stimuli and, more precisely, with the different instances of the two categories of positive and negative facial stimuli, respectively, that have been presented in the experimental works of Nothdurft (1993), White (1995), Fox et al. (2000), Öhman et al. (2001) and Eastwood et al. (2001).

The aim of the studies mentioned has been to test the threat-advantage hypothesis (or a variant of it). The results, however, were heterogeneous. Three studies found steep RT set-size functions (Fox et al., 2000; Nothdurft, 1993; Öhman et al., 2001), revealing inefficient or even very inefficient searches, whereas one study (White, 1995) found efficient searches, and one study (Eastwood et al., 2001) found search performance in the vicinity of efficient search. Two studies (Eastwood et al., 2001; Fox et al., 2000) found more efficient (or: less inefficient) searches for negative-face targets, whereas three studies did not find differences in search slopes for either target (Nothdurft, 1993; Öhman et al., 2001; White, 1995). Two of the latter studies (Öhman et al., 2001; White, 1995) found differences in the intercept parameter of the RT set-size function, which, however, does not relate to the issue of preattentive versus attentive search but to processes preceding or following search (e.g., the final decision that a target has been found).

One obvious conclusion that may be drawn from the heterogeneous results is that there is no preattentive detector for facial threat. In fact, the heterogeneity of the results is quite expected if the stimuli in the studies are not mainly seen as equivalent members of the categories "facial threat" and "facial friendliness", but rather as perceptually different stimuli. That visual search tasks that present different stimulus pairs yield different search efficiencies certainly comes as no surprise if the results are interpreted at their face value: as tests of different configurations of different perceptual features. Thus, visual search with one pair may be hard because the stimuli are relatively complex and crowded configurations of perceptual features that need elaborate perceptual processing, while visual search with another pair may be easy because the particular graphic layout provides perceptual features that can be used to guide attention. And, of course, there is no guarantee that a single perceptual dimension underlies the variation of search efficiency between stimulus pairs.

However, a proponent of the preattentive-detector hypothesis might not accept this conclusion because the studies differed not only with respect to the stimulus pair tested, but in other procedural details (e.g., stimulus sizes and densities, set sizes and presentation layout, display times, etc.; see Horstmann, 2007, for details) as well. Thus, it may be possible to explain the variation in search efficiency by the variation in these procedural details, rather than by the variation of the perceptual layout of the stimuli. Moreover, neither of the studies provided evidence that pop-out would be detected if adequate stimuli are presented. Thus, Horstmann (2007) tested replicas of the stimuli presented by White (1995), Fox et al. (2000), and Öhman et al. (2001), in a constant experimental procedure after securing in a separate test that it actually replicates a classical search asymmetry with non-facial stimuli (Treisman & Souther, 1985). The results of this "bench-mark-test" showed: (a) inefficient searches for all stimulus pairs; (b) more efficient (or: less inefficient) searches for the negative face targets among the positive face distractors (although this effect was very weak for the Öhman et al., 2001, stimuli); and (c) considerable variability of search efficiency between stimulus pairs. Horstmann (2007) concluded that a critical test had failed to provide striking support for the preattentive threat-detector hypothesis, because none of the negative stimuli popped out of the positive crowds, and because search efficiency was quite different for different stimulus pairs.

But what about the replicable difference in search efficiency between the positive and the negative faces? Indeed, some researchers (e.g., Eastwood et al., 2001) would probably count the less inefficient search for negative than positive target faces (henceforth: a relative search asymmetry as opposed to the classical search asymmetry, where search for one of the faces is efficient) as evidence for preattentive processing. Horstmann (2007) conceded that a relative search asymmetry may indeed result when a preattentive detector is only weakly activated; however, when considering that positive-face and negative-face stimuli necessarily differ in their perceptual features, one naturally arrives at the hypothesis that the relative search asymmetry can well be due to perceptual differences between the stimuli, but not their emotional meaning.

## Overview and rationale of the present experiment

The present study can be conceived of as comprising five single experiments, each of which tested visual search efficiency for one pair of stimuli in a search asymmetry design. The stimuli were constructed to be replicas (based on the figures in the respective publications) of stimuli used by Nothdurft (1993), White (1995), Fox et al. (2000), Öhman et al. (2001) and Eastwood et al. (2001). For ease of communication, these stimulus pairs are henceforth named the Nothdurft stimuli, the White stimuli, the Fox stimuli, the Öhman stimuli, and the Eastwood stimuli. The basic design was closely modelled to the one frequently used in visual search experiments (e.g., Enns & Rensink, 1990; Rauschenberger & Chu, 2006; Treisman & Gormican, 1988; Treisman & Souther, 1985). Participants completed five pairs of blocks of trials. In each block of a pair, they were presented with display sizes of 1, 6, and 12 facial stimuli. Blocks within a pair differed with respect to the identity of the target and the identity of the distractors. In addition to set size, trials differed depending on whether a target was presented (target-present trials) or not (target-absent trials). Each of the 12 conditions that resulted from the orthogonal combination of set size × target identity × target presence was repeated 25 times within a pair of blocks. Dependent variables were RT and error proportions. Pairs of blocks differed with respect to the tested stimuli. The serial position of pairs of blocks (or subexperiments) was balanced using a Latin square.

The experiment was conducted with two aims: The first, and more general, aim was to replicate and complete the assessment of search efficiency for different pairs of faces showing positive or negative facial expressions, in order to see which of the effects were relatively stable, and which varied with stimulus pair. Two advances were made with respect to previous research (Horstmann, 2007): First, a wider range of stimulus pairs from the literature was tested to enhance the external validity of the experiments and thus decrease the probability of drawing conclusions that pertained only to particular stimulus configurations. In order to see the generality and specifics of different stimulus pairs, the present study tested the experimental stimuli of five frequently cited studies on the threat-detector hypothesis, which covered a relatively wide range of stimulus configurations. Second, a within-participants design was used, securing that even random fluctuations between sample populations have no effect on the comparisons between facial-stimulus pairs. Finally, sample size was large enough ($N = 20$), to secure internal validity and experimental power.

As to the second aim, the adoption of a within-participants design allows for a test of more specific hypotheses. As said before, the literature suggests that search slopes vary considerably not only between the categories of threat (or negative valence) and friendliness (or positive valence), but also between the facial-stimulus pairs tested. This is contrary to what one would expect if search efficiency is predominantly due to an underlying dimension of threat or negative valence.

This rather general statement can be rendered more precisely as follows: If threat is a preattentively available feature, which is present to some degree in the negative-face stimuli, but absent in the positive-face stimuli, we would expect that variables other than facial threat would have relatively little effect on negative-face search-efficiency, while we would expect a relatively strong influence of these variables on positive-face search-efficiency. In particular, efficient or nearly efficient search would be expected for the negative-face targets of all pairs. In contrast, search efficiency with a friendly face target would be expected to be low, and to vary considerably with the particular layout of the stimulus pair. This is because, according to the threat-advantage hypothesis, there is no facial-friendliness detector, and the target face must therefore be searched for on the basis of a demanding perceptual analysis. The demands of the perceptual analysis should vary with perceptually different stimulus pairs, because some of the stimulus pairs are relatively complex while others are rather redundant (e.g., Rauschenberger & Yantis, 2006).

It is important to note that it is not just argued that search efficiency for negative-face targets varies less than for positive-face targets (according to the threat-advantage hypothesis). What is more, the threat-advantage hypothesis predicts that search for negative-face and positive-face targets is influenced by different variables: Search for negative-face targets varies according to perceived threat, while search for positive-face targets varies according to perceptual differences. Thus, the threat-advantage hypothesis predicts that search efficiency for a negative-face target is uncorrelated with search efficiency for a positive-face target, because search for the negative-face targets is guided a by single feature (i.e., threat, or negative valence), while search for the positive-face targets is governed by principles of demanding perceptual search. On the other hand, if both searches (for a negative-face and for a positive-face target) rely on similar perceptual analyses, search efficiency for both types of targets should be highly correlated.

Since the present experiment tests five perceptually different stimulus pairs in a within-participants design, it is additionally possible to test the validity of an observation derived from previous research concerning stimulus complexity or naturalness. In particular, previous research suggests that relatively simple and artificial stimuli, such as the stimulus pair tested by Eastwood et al. (2001), yield more efficient search slopes than the more complex and natural stimuli, such as the stimuli tested by Nothdurft (1993) or Öhman et al. (2001). As mentioned before, the interpretation of the extant data is complicated by the fact that comparisons between different stimulus pairs relies on comparisons between different experiments. Because all stimulus pairs in the present study are tested within the same experiment with the same participants, it is possible to evaluate the observation on a more secure data base. Of course, if the search efficiency for negative faces were higher with relatively less naturalistic stimuli and lower with relatively naturalistic stimuli, the idea of an evolved threat detector that drives search efficiency for negative faces becomes somewhat unconvincing.

Finally, it has been proposed that differences in search efficiency with positive and negative faces are not primarily due to attentional guidance by the target but to differential efficiency in distractor rejection (e.g., Fox et al., 2001; Horstmann et al., 2006b). This hypothesis predicts that search efficiency from target-absent trials, where attentional guidance by the target cannot influence search efficiency, which must therefore exclusively be driven by distractor rejection, is highly correlated with search efficiency from target-present trials where the influences of attentional guidance by the target and distractor rejection are combined.

# METHOD

## Participants

These were 20 students or visitors from Bielefeld University, 6 men and 14 women, with a mean age of 23 years ($SD = 5.1$). They participated voluntarily, mostly in partial fulfilment of examination requirements.

## Apparatus

The experiment was administered with a PC equipped with a 80486 CPU, connected to a colour monitor (screen 27 × 21 cm; viewing distance was 1 m) for stimulus presentations, and to a keyboard used to collect the manual responses. Stimulus presentation was white on black.

## Stimuli

The stimulus pairs are depicted in Figure 1. They were constructed using CorelDraw© based on the respective figures in previous publications, and then converted into bitmaps. The White stimuli and the Eastwood stimuli had a diameter of 2.3 cm (1.3° of visual angle). The horizontal and vertical axes of the oval Fox stimulus measured 2.3 × 2.6 cm (1.3° × 1.5°), of the Öhman stimuli 2.6 × 3.1 cm (1.5° × 1.8°), and of the Nothdurft stimuli 2.8 × 2.6 cm (1.5° × 1.6°). All stimuli forming a pair differed only with regard to the curvature of the mouth, except for the Öhman stimulus pair, which differed with regard to the brows and the eyes as well.

## Design

Sixty experimental conditions were tested, resulting from the orthogonal combination of Stimulus Pair (White vs. Eastwood vs. Nothdurft. vs. Öhman vs. Fox) × Target Type (positive vs. negative face) × Target Presence (present vs. absent) × Set Size (1 vs. 6 vs. 12). All conditions were tested within participants. Target presence and set size varied randomly within a block of trials, target type varied systematically between blocks in an ABAB or a BABA pattern (balanced over participants), stimulus pair varied between pairs of blocks, with serial position balanced over participants following a Latin square. Whether presence versus absence of the target stimulus was indicated by the left or the right response key (SR-mapping) was also balanced over the participants. The methods variables (target type in the first

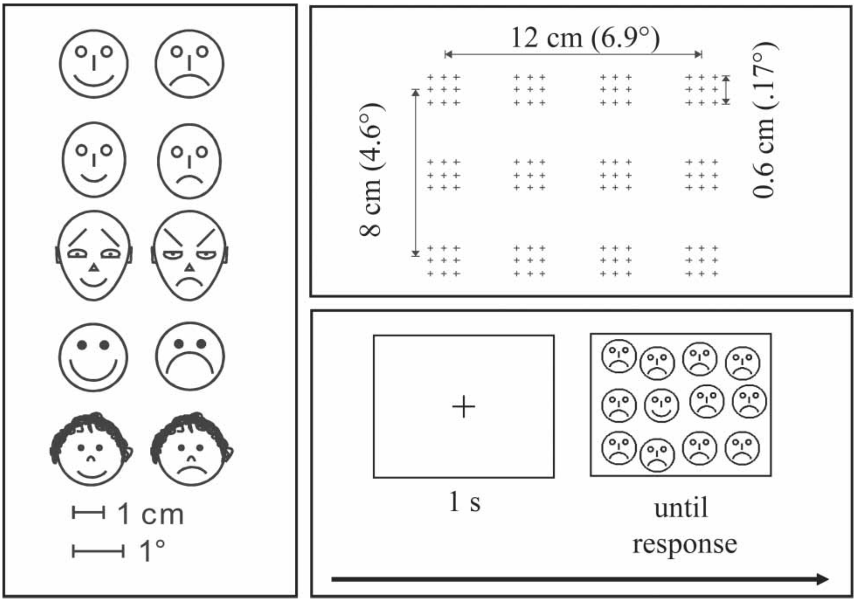


**Figure 1.** Overview of the stimuli used in the present experiments. Left: The stimuli were intended to be replicas of the (from top to bottom) stimuli from: White (1995), Fox et al. (2000, Experiment 5), Öhman et al. (2001, Experiment 3), Eastwood et al. (2001, Experiment 1), and Nothdurft (1993, Study 5). Right top: Each cross indicates a possible position for a stimulus (note that within a nested 9-cross block, only one stimulus could appear). Right bottom: Sequence of events within a trial.



block, SR-mapping, and order of stimuli) were orthogonally combined to yield 20 different between-participants conditions.

## Procedure

In each trial, 1, 6, or 12 facial stimuli (see Figure 1) were presented within a monitor area of $12 \times 8$ cm ($6.9^\circ \times 4.6^\circ$). Individual faces were presented in a (invisible) 4 (horizontal) $\times$ 3 (vertical) matrix (see Figure 1). Average positions were altered by random displacement, separately computed for each position in each given trial. In particular, the average position of a stimulus was the centre of a $3 \times 3$ grid, and the actual position of the stimulus was randomly chosen from the resulting 9 positions. The distance of adjacent positions in the grid was 3 mm ($0.17^\circ$). This procedure resulted in a moderately irregular arrangement of the stimuli, intended to eliminate possible supra-stimulus cues to the target's position (Duncan & Humphreys, 1989). The sequence of conditions within a block was randomised.

Participants were fully informed about their task and the structure of the experiment by means of written and oral instructions. Each pair of blocks was preceded by the announcement of the upcoming stimulus pair as well as the identity of the target in the following trials before each block. For example, participants were told that they should search for the friendly face and indicate with the correct response key its presence or absence. Participants then worked on 20 practice trials, which were followed by 150 experimental trials. The second block had the same structure.

Each trial began with the 1000 ms fixation cross presentation, immediately followed by the faces display. The faces display remained until a response was made. A trial was aborted if no response was made within 6 seconds. If participants pressed the wrong key, a 100 ms tone served as error feedback. The ITI was 1100 ms.



## Data treatment

For the analysis of RTs, RTs $< 200$ ms or $> 3000$ ms, and errors, were excluded (the RT cut-off involved less than 1% of the trials). Mean reaction times for each of the 60 experimental conditions were calculated. Because the predictions for preattentive processing concerns the slopes of the RT–set-size functions, individual estimates of the two parameters $b$ (slope) and $a$ (intercept) were computed for each of the four conditions that result by crossing the two variables target presence (present vs. absent) and target identity (happy vs. angry). That is, linear regressions were computed, separately for each participant, with RTs for the three set-size conditions as the dependent variable, and with set size (1, 6, 12) as the independent variable. Further analysis was done using the regression parameters. For the analysis of the errors, error scores were computed as the proportion of false responses. Analogous to the RT analysis, the statistical tests were performed on the slope and intercept parameters.

# RESULTS

## Slopes

Figure 2 shows the grand means for RTs and errors of Experiment 1. Table 2 reports the mean slopes and intercepts. The mean slopes for the RTs are additionally depicted in Figure 3 to better allow for comparisons between the stimuli.

The slopes for the RTs were analysed by a 5 (Stimulus Pair: White, Fox, Öhman, Eastwood, Nothdurft) $\times$ 2 (Target Type: positive vs. negative) $\times$ 2 (Target Presence: presence vs. absence) analysis of variance (ANOVA). Table 1 gives a structured overview over the results of the ANOVAs. The ANOVA revealed significant main effects for all variables, stimulus pair: $F(4, 76) = 52.7, p < .001$; target type: $F(1, 19) = 105.7, p < .001$;

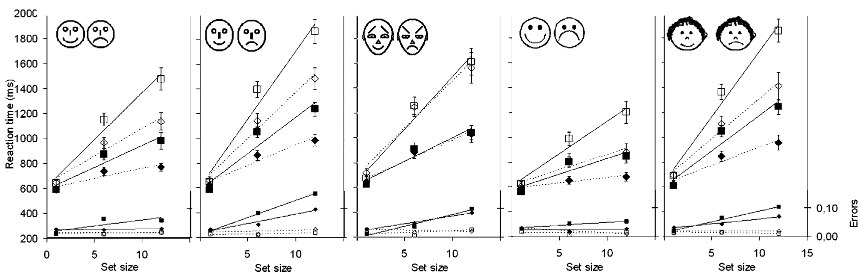


**Figure 2.** Mean correct RTs and error rates for each of the 12 conditions for all five stimulus pairs. Filled symbols represent target present trials and unfilled symbols target absent trials. Diamonds code for trials with a negative face target, whereas squares code for trials with a positive face target. Error bars show the standard error of the means. The figure also displays the linear trends obtained by linear regression analysis.



and target presence: $F(1, 19) = 92.5$, $p < .001$; note that here and henceforth, effects of stimulus pair were Huynh–Feldt corrected for violations of the sphericity assumption where necessary; to retain readability, however, the uncorrected degrees of freedom are reported. The main effect for stimulus pair reflected the fact that search efficiency varied considerably with the stimulus pair, replicating previous results (see Table 2). The main effect for target type reflects that search was more efficient in blocks where the

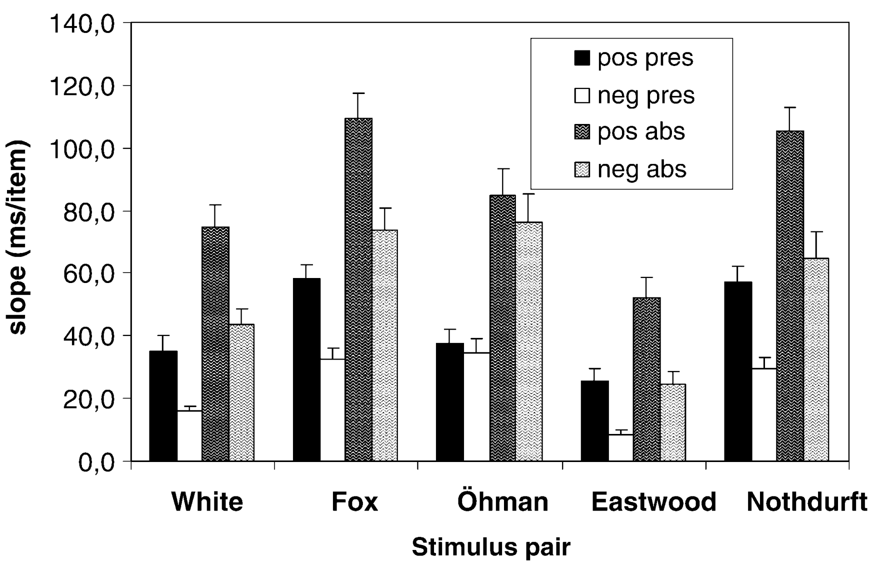


**Figure 3.** Search slopes for target present and target absent trials with positive and negative face targets for all five stimulus pairs. Error bars show the standard error of the means.

TABLE 1
Summary of the *F*-values from the ANOVAs on the search slopes and the intercepts, for the RT data and the error data, respectively

| | *Slope* | | *Intercept* | |
|---|---|---|---|---|
| | *RT* | *Errors* | *RT* | *Errors* |
| Stimulus Pair (SP) | **52.7** | **10.1** | **5.6** | 1.5 |
| Target Presence (TP) | **92.5** | **51.2** | **8.8** | 0.5 |
| Target Type (TT) | **105.7** | **7.5** | 2.2 | 3.7 |
| SP × TP | **13.5** | **5.8** | 0.8 | 0.8 |
| SP × TT | **10.4** | 0.1 | 0.5 | 0.6 |
| TP × TT | **14.9** | **5.1** | 1.2 | 0.0 |
| SP × TP × TT | 0.6 | 1.4 | 1.4 | 1.0 |

*Notes*: For all *F*s involving stimulus pair, nominator *df* was 4 and denominator *df* was 76; For all remaining *F*s, nominator *df* was 1 and denominator *df* was 19. **Emboldened** values exceed the critical $F = 2.49$, $p = .05$, or $F = 4.38$, $p = .05$, respectively.

negative target had to be searched for than in blocks where the positive target had to be searched for (40 vs. 64 ms/item). The main effect for target presence, finally, reflected the well-known pattern of more efficient search in target present trials than in target absent trials (34 vs. 71 ms/item). This effect is predicted on the assumption of serial self-terminating search: Whereas in target-absent trials, all stimuli have to be examined before it can safely be concluded that the target is absent, in target-present trials, search is terminated as soon as the target is found. Whether the target is found, for example, in the first examined stimulus, the third, or the last, depends on chance; hence, the mean number of elements that are examined before the target is found is set size/2.

The two-way interactions were significant as well. The Stimulus Pair × Target Type interaction, $F(4, 76) = 10.4$, $p < .05$, reveals that the advantage in search efficiency when the negative rather than the positive face target is searched for depends on the stimulus pair, with the smallest advantage for the Öhman stimulus pair (6 ms/item), and the largest advantage for the Fox stimulus pair (30 ms/item). The Stimulus Pair × Target Presence interaction, $F(4, 76) = 13.5$, $p < .001$, reveals that the effect of target presence depends on stimulus pair. As the ratio of search slopes in target-present to target-absent trials was approximately 1:2 with all stimulus pairs (White: 2.6; Fox: 2.1; Öhman: 2.3; Eastwood: 2.6; Nothdurft: 2.0), consistent with the assumption of a serial self-terminating search, this effect could be accounted for by differences in overall search efficiency. Finally, the Target Type × Target Presence interaction, $F(1, 19) = 14.9$, $p = .001$, reflects that the target presence had a stronger effect on search slopes in blocks where a positive target is searched for than in blocks where a negative target is searched for.

TABLE 2
Summary of the search slopes and the intercepts for the RT and the error data, respectively in Experiments 1–4

| *Stimulus pair* | | *Slope* | | *Intercept* | |
|---|---|---|---|---|---|
| | | *RT* | *Errors* | *RT* | *Errors* |
| *White* | | | | | |
| | PTP | 35.1 | 0.004 | 592.8 | 0.019 |
| | NTP | 16.0 | 0.000 | 597.1 | 0.027 |
| | PTA | 74.8 | 0.000 | 616.2 | 0.011 |
| | NTA | 43.7 | 0.000 | 639.1 | 0.016 |
| *Fox* | | | | | |
| | PTP | 58.4 | 0.012 | 588.4 | 0.011 |
| | NTP | 32.6 | 0.006 | 618.8 | 0.017 |
| | PTA | 109.4 | 0.001 | 610.1 | 0.008 |
| | NTA | 73.9 | 0.001 | 629.3 | 0.017 |
| *Öhman* | | | | | |
| | PTP | 37.6 | 0.008 | 621.6 | −0.003 |
| | NTP | 34.5 | 0.005 | 634.2 | 0.019 |
| | PTA | 84.7 | 0.001 | 644.6 | 0.008 |
| | NTA | 76.1 | −0.001 | 695.9 | 0.026 |
| *Eastwood* | | | | | |
| | PTP | 25.6 | 0.002 | 573.6 | 0.027 |
| | NTP | 8.4 | 0.000 | 587.8 | 0.023 |
| | PTA | 52.1 | 0.000 | 608.3 | 0.013 |
| | NTA | 24.5 | −0.002 | 612.7 | 0.030 |
| *Nothdurft* | | | | | |
| | PTP | 57.3 | 0.008 | 605.2 | 0.013 |
| | NTP | 29.7 | 0.003 | 621.4 | 0.027 |
| | PTA | 105.6 | 0.000 | 636.1 | 0.014 |
| | NTA | 64.8 | 0.000 | 660.7 | 0.017 |

*Note*: PTP = friendly target present; NTP = angry target present; PTA = friendly target absent; NTA = angry target absent.



Again, as the present-to-absent ratio is 2:1 for all blocks, this effect probably reflects differences in search efficiency as already reflected in the main effect for stimulus pair. The three-way interaction was not significant.

The corresponding ANOVA of the slopes for the error proportions revealed significant main effects for all factors, stimulus pair: $F(4, 76) = 10.1$, $p < .001$; target type: $F(1, 19) = 7.5$, $p < .05$; and target presence: $F(1, 19) = 51.2$, $p < .001$. The slopes for the error proportions are in the same direction as the RTs for stimulus pair and target type, that is, as a general trend, errors are more frequent in conditions with long RTs. For target presence, error slopes were steeper in the target-present than in the target-absent condition, indicating that targets were frequently missed in target-present trials. This implies a moderate speed–accuracy trade-off relevant to the interpretation of the main effect for target presence. The Stimulus Pair × Target Presence interaction, $F(4, 76) = 5.8$, $p < .001$, and the Target Identity × Target Presence interaction, $F(1, 19) = 5.1$, $p < .05$, were also significant, indicating that the size of the target presence effect was different for the stimulus pairs (in fact, it was considerably smaller in the more easy searches, that is, with the White and the Eastwood stimulus pairs), and that the effect was stronger for searches among negative than positive faces.

## Intercepts

The ANOVA of the intercepts for the RTs revealed a main effect for Stimulus, $F(4, 76) = 6.6$, $p < .01$, and Target Presence, $F(1, 19) = 8.8$, $p < .01$. The other effects were not significant, $F\text{s} < 2.2$, $p\text{s} > .15$.

The intercept for RTs was highest for the Öhman stimuli (649 ms) and lowest for Eastwood stimuli (596 ms). Also, the intercept for the RTs was higher in target absent conditions than in target present conditions (629 ms vs. 609 ms). Intercept effects reflect differences that occur before or after the search and the relative low intercept for the RTs with the Eastwood stimuli may have something to do with the relative simplicity of the stimuli, which enabled a faster segregation of figures–ground relationships than, for example, the more complicated Öhman stimuli. The effect of target presence, in contrast, is most probably due to differences after the search had been completed. That the intercept was higher in the target-absent condition is plausible, assuming that the participants hesitated longer before responding when they had not found a target than when they had found the target.

A corresponding analysis of the intercepts for the errors revealed no significant main effects or interactions at all, although the main effect for emotion approached significance, $F(1, 19) = 3.7$, $p < .07$. More errors were made with positive targets, which is consistent with the RT data.

## Additional analyses

The threat-advantage hypothesis predicts that search for negative-face targets should be efficient (or almost efficient) for all stimulus pairs, while particulars of the graphic layout should have little influence on performance. This is based on the assumption that these targets are not searched for on the basis of a perceptual analysis but rather by direct preattentive access of the underlying emotional feature. In contrast, search for a positive-face target is expected to vary with particulars of the graphic layout, because the search is performed on the basis of a perceptual analysis. As can be seen from Figure 2, the threat-advantage hypothesis is not well supported by the present data, because the efficiency for the negative-face target varies with stimulus pair. Moreover, the correlation between the mean search efficiency for negative-face targets and the mean search efficiency for positive-face targets is $r = .743$ for target-present trials and $r = .857$ for target-absent trials. Thus, there is a substantial correlation over different stimulus pairs, suggesting that factors that complicate the search for the positive face target of a pair also complicate the search for the negative-face target of the pair. The reason why the correlation is not even higher is because the Öhman stimuli show practically no difference between the two targets. If the correlation is computed only for the four other stimulus pairs, the correlations are $r = .996$ and $r = .993$ for target present and absent trials, respectively.

Horstmann et al. (2006b) have proposed that the search for schematic faces is not predominantly governed by attentional guidance by the target, but rather by more or less efficient distractor rejection. This hypothesis suggests that search efficiency in target-absent trials, where distractor rejection is the only possible means to accomplish the task because no target is present that could possibly guide attention, and search efficiency in target-present trials, is highly correlated. This turns out to be true with the correlations being $r = .976$ and $r = .995$, for negative-face and positive-face target trials, respectively.

The third additional analysis concerned the role of stimulus simplicity. Based on a count of the facial features, the present stimulus set can be ordered with respect to simplicity as follows: Eastwood (eyes and mouth); White and Fox (eyes, mouth and nose); Nothdurft (eyes, mouth, nose and hair); and Öhman (eyes, mouth, nose, brows and ears). Figure 2 suggests that stimulus simplicity is inversely related to search efficiency. This impression is supported by a one-way ANOVA of the negative-face target-present conditions with the factor simplicity (two, three, four, five features), $F(3, 57) = 27.5$, $p < .001$. Post hoc tests (least significant difference) revealed significant differences between all conditions except between the Nothdurft and Öhman stimuli.

## Additional data

I have made claims about certain attributes of the stimuli that were not based on data but rather on face validity: one claim about the naturalness of the stimuli and one about perceived threat. Because this is unfortunate, in particular when relevant data can be easily obtained, I gathered additional data concerning the perceived naturalness and perceived threat of the faces. Two independent random samples of 20 participants from the same population as for the visual-search data were recruited. Each participant was individually presented with separate paper printouts of the 10 stimuli used in the experiments (about $2 \times 2$ cm), and asked to put them in a rank order from unnatural (left) to natural (right), or non-threatening (left) to

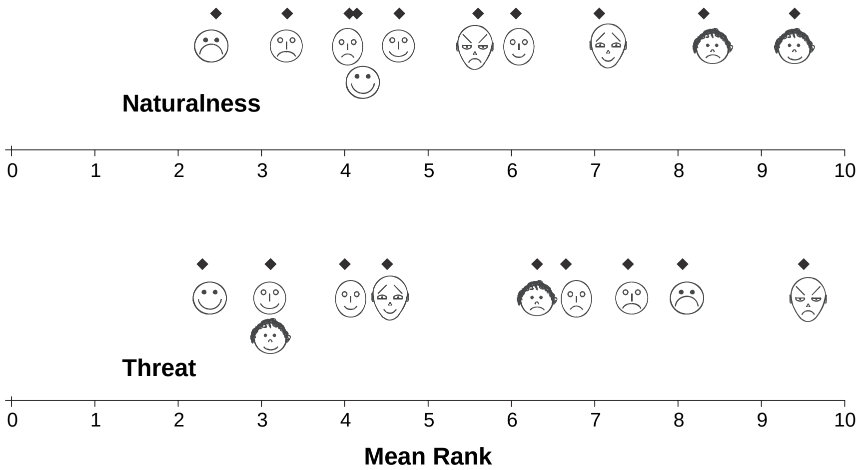


**Figure 4.** Mean ranks for naturalness and threat for the 10 faces.

threatening (right). The rank-order task was done manually (by moving the printouts around), and when the participant finished, the experimenter recorded the stimulus order. Ties were not allowed. Figure 4 shows the mean ranks for (a) naturalness and (b) threat. As can be seen, the empirical data are consistent with the claims made earlier. The order of naturalness is Eastwood, White, Fox, Öhman, Nothdurft, and quite unanticipated, friendly faces are ranked as more natural than angry faces. An ANOVA of the naturalness rankings as the dependent variable and Stimulus Pair (Eastwood vs. White vs. Fox vs. Öhman vs. Nothdurft) and Affect (positive vs. negative) as the independent variables corroborates this picture, Stimulus: $F(4, 76) = 23.13$, $p < .001$; Affect: $F(1, 19) = 33.82$, $p < .001$; Interaction: $F = 1.4$.

Finally, the faces differed as to their perceived threat within and between pairs. The smiling stimuli were rated as less threatening than the frowning stimuli, Stimulus: $F(4, 76) = 11.91$, $p < .001$; Affect: $F(1, 19) = 67.70$, $p < .001$; Interaction: $F(4, 76) = 7.68$, $p < .001$.

Whether the subjective stimulus dimensions would explain variance in the objective search data was also examined. Table 3 shows the first-order correlation coefficients. To point out the most important results, naturalness correlates highly and significantly with search efficiency, while the (negative) correlation of search efficiency and threat was weaker and nonsignificant.

Next, partial correlations were computed. When threat was held statistically constant, naturalness correlated significantly with all objective variables. What is more, the correlation between naturalness and search efficiency was still significant. When naturalness was held statistically constant, the correlations between threat and the slope parameters stayed

TABLE 3
Correlations of the subjective data, stimulus rankings of naturalness and threat, and the objective data, slopes and intercepts for target present trials (TP) and target absent trials (TA)

| | *Threat* | *Slope TP* | *Slope TA* | *Intercept TP* | *Intercept TA* |
|---|---|---|---|---|---|
| *Naturalness* | −.34 | **.73** | **.72** | .44 | .37 |
| *Threat* | — | −.51 | −.44 | .53 | .61 |
| *Slope TP* | | — | **.99** | .15 | .02 |
| *Slope TA* | | | — | .27 | .11 |
| *Intercept TP* | | | | — | **.87** |
| *Intercept TA* | | | | | — |

*Note*: Correlations >.61 (**emboldened**) are significant at $p < .05$.



low; however, a very high correlation between threat and the intercept parameters emerged (Table 4).

## DISCUSSION

The present experiment permits a direct comparison of the effects of emotion category and stimulus pair on search efficiency by testing several stimulus pairs in a within-participants design. A first question to be answered was which effects in visual search are relatively stable over different stimulus pairs, and which are not.

As to the relatively stable effects, a search was consistently more efficient in blocks with negative-face targets than in blocks with positive-face targets, although the difference was minimal with the Öhman stimuli. This result has two implications: first, particulars of the method do indeed appear to have some impact on the results and, second, the relative search advantage for angry targets is probably more robust a phenomenon than a review of previous studies suggests (see introduction). A consistent second result was

TABLE 4
Partial correlations of the subjective data, stimulus rankings of naturalness and threat, and the objective data, slopes and intercepts for target-present trials (TP) and target-absent trials (TA)

| | *Slope TP* | *Slope TA* | *Intercept TP* | *Intercept TA* |
|---|---|---|---|---|
| Naturalness | **.68** | **.68** | **.77** | **.77** |
| Threat | –.41 | –.31 | **.80** | **.84** |

*Notes*: The first row shows the partial correlations for naturalness while holding threat constant, and the second row shows the partial correlations for threat while holding naturalness constant. Significant correlations are **emboldened**.

that neither stimulus pair revealed a classical search asymmetry; rather, the search for all target faces was inefficient (with an exception of Eastwood et al.'s, 2001, negative stimuli, where performance was in the vicinity of the "quite efficient" Wolfe, 1998, search). While this result is not literally inconsistent with a preattentive detector for negative faces, it nevertheless does not support it. In fact, given the rather consistent failure to obtain evidence for the threat-detector hypothesis (i.e., efficient search) within the most suited experimental paradigm to test this type of hypothesis (i.e., the visual search paradigm), one naturally arrives at the conclusion that "faces (familiar, upright, angry, and so on)" are among the "probable non-attributes", which are "suggested guiding features where the balance of evidence argues against inclusion on the list [of guiding features]" (Wolfe & Horowitz, 2005, p. 6). This conclusion is also fostered by the third very consistent result, being the present-to-absent slope ratios. These are, without exception, equal to or somewhat larger than 1:2, which is consistent with a serial, self-terminating search.

A fourth very consistent result was that the difference in search efficiency that was revealed in target-present trials was also revealed in target-absent trials. This results pattern has already been observed (e.g., Fox et al., 2001; Horstmann, 2007; Horstmann et al., 2006b), but its consistency is revealing: That the search was more efficient when all faces were positive than when all faces were negative strongly supports the hypothesis that differences in the ease of distractor rejection, rather than differences in attentional guidance by the target, cause the overall differences in search efficiency between positive and negative faces. This too, of course, argues against the preattentive-detector hypothesis.

The main variability concerned overall search efficiency, which was strongly affected by stimulus pair. This result was expected on the assumption that search is based primarily on a perceptual analysis, because if perceptually different pairs of stimuli are tested (faces or other), one expects some searches to be hard and some easy, depending on whether the particular stimulus configuration permits some attentional guidance or not (Wolfe, 1998), and depending on whether the target and the distractor are similar or dissimilar (Duncan & Humphreys, 1989).

The between-participants design used in this study allowed for a test of two more-specific hypotheses. The threat-detector hypothesis predicts that the detection of an angry-face target is achieved as a basic-feature search, whereas the detection of a friendly-face target is achieved as an attentively demanding conjunction search; thus, these searches are based on different processes and their efficiency should thus be relatively uncorrelated. However, the prediction was refuted since the results showed that search efficiency for the five angry-face targets was highly correlated with search efficiency for the corresponding friendly face targets. This result was predicted on the assumption that search performance relies on the same mechanism of perceptual analysis. It might be objected that in friendly-face target-present trials, the crowd of distractors consists of angry faces, and that the correlation might be explained by assuming that the angry-face distractors in this condition drew attention or inhibited the disengagement of attention (e.g., Fox et al., 2000). However, an equally high correlation was also obtained for the target-absent trials that consisted of homogeneous crowds of angry or friendly stimuli, respectively. Thus, the original conclusion that search performance with angry-face and friendly-face stimuli is apparently based on similar perceptual processes appears to be valid. Moreover, this result is consistent with the insight that an important determinant of search efficiency is the *relation* between target and distractors (Duncan & Humphreys, 1989), in particular their perceptual discriminability (or its opposite: similarity).

We also tested whether distractor rejection, rather than attentional guidance by the target, is an important determinant of search efficiency. The results showed that search efficiency for target-present and target-absent trials is nearly perfectly correlated. This is consistent with the hypothesis that distractor rejection is the prime determinant of search efficiency (Horstmann et al., 2006b), at least when the target cannot be detected by a basic feature search, and a more elaborate conjunction search must therefore be conducted.

Additional data were collected regarding perceived naturalness and perceived threat. These data corroborated the assumptions that the used faces differ in their perceived naturalness and in their perceived threat. In particular, the results strengthen the concern that efficient search and naturalness are inversely correlated. In fact, there was a strong correlation between naturalness and search efficiency, indicating that the search was more efficient with more simple and less natural stimuli. As argued in the introduction, this is not expected under the assumption that search efficiency is driven by an evolved threat detector. Search efficiency was only moderately (and not significantly) correlated with threat—however, when the effects of naturalness are statistically held constant, threat correlated significantly with the intercept parameters of the search functions.

The present results thus confirm the impression based on previous research that the naturalness of the faces is inversely related to search efficiency: search with simple but less naturalistic looking faces is almost efficient, whereas search with complex but more naturalistic faces is very inefficient. This result might be seen as a qualification to Tipples et al.'s (2002) conclusion that the threat-advantage effect is obtained only with face-like stimuli. In Tipples et al.'s study, stimuli that included critical features of Öhman-like stimuli but did not look like faces (according to a rating study) showed no threat advantage in visual search, whereas face-like stimuli did (note, however, that in that study set size was not manipulated and that search efficiency was thus not the dependent variable). As all stimuli in the present study are face like and all revealed more efficient processing of negative faces, there is no actual contradiction to Tipples et al.'s study. However, the present results show that an extension of Tipples et al.'s conclusion cannot be corroborated: that the threat-detector hypothesis is best supported with most naturalistic stimuli.

What is the most parsimonious explanation of the results? In my view, the results are most consistent with serial self-terminating searches that vary in difficulty depending on the stimulus pair and on the present target. Stimulus simplicity and naturalness are obvious factors here. Assuming that searches are more inefficient with more complex stimuli would partly explain the more efficient searches with the more simple stimuli (Eastwood and White) as opposed to the less efficient searches with the more complex stimuli (Öhman and Nothdurft). Stimulus simplicity, however, gives a poor account of the difference between the Fox and the White stimuli, because these stimuli did not obviously differ in complexity, but mainly in the shape of the head. Differences in within-pair target-distractor similarity (Duncan & Humphreys, 1989) might help to explain the difference between the Fox and the White stimuli. The mouths in the White and Eastwood stimuli are larger than in the remaining stimuli,[2] such that target and distractor are less similar and better discriminable than the other stimuli where the mouth is rather small.

That blocks with negative-face targets yield more efficient searches than blocks with positive-face targets can be accounted for by two types of explanations—one perceptual, and one emotional. Finding a positive-face target in a negative-face crowd may be more difficult than vice versa for simple perceptual reasons. For one, grouping by similarity and proximity may render the mouth in the positive face more difficult to separate from the face's outline than the mouth in the negative face (e.g., White, 1995).[3] Thus, it is possible that searching for the positive face comes near to searching for a target that is characterised by an absent feature, which is known to result in very inefficient search (cf. Wolfe, 2001). Alternatively, or in addition, search through negative-face crowds may be slower than search through positive-face crowds (e.g., Fox et al., 2000; Horstmann et al., 2006b). That the efficiency of distractor rejection was an important factor in the present experiments is evident from the target-absent trials: For all stimulus pairs,

[2] In fact, unpublished data from our lab show that search efficiency is a function of the curvature of the mouth.

[3] In a yet unpublished paper, Horstmann, Bergmann, Burghaus, and Becker report on evidence that perceptual grouping is indeed a main factor for the facial valence effect with schematic faces.

target-absent trials yielded shallower search slopes through crowds consisting entirely of negative faces than through crowds entirely made up of positive faces. This result strongly indicates that the reported effects are due to more efficient rejection of positive-face distractors (as compared to negative-face distractors), but not to the more efficient detection of negative-face targets (as compared to positive-face targets). The ease of distractor rejection has been hypothesised to be a function of distractor homogeneity (Duncan & Humphreys, 1989). This hypothesis would imply that positive-face distractors are more homogeneous than negative-face distractors. Because the distractors, if present, were identical replicas of each other in all conditions, Duncan and Humphrey's hypothesis does not appear to be applicable on first sight. However, positive-face distractors may be regarded as more self-similar than negative-face distractors, in that the mouth shape repeats the faces outline only in the positive-face distractors, but not in the negative-face distractors (Horstmann et al., 2006b). Similarly, Rauschenberger and Yantis (2006) have proposed that differential stimulus redundancy, which is a concept kindred to self-similarity, may explain some search asymmetries, where more redundant distractors are encoded faster than less redundant distractors, leading to more efficient search with redundant distractors.

More efficient rejection of positive-face distractors is also consistent with an emotional account that negative-face distractors, because of their negative valence, bind attention longer than positive-face distractors (Fox et al., 2000). Note that this hypothesis, although it invokes emotional factors as the original threat-advantage hypothesis does, constitutes a very different type of explanation. While the threat-advantage hypothesis states that negative affect is processed preattentively, the attentional-binding hypothesis holds that the observed effects are post-attentive: The attentional processing of negative-face distractors lasts longer than the attentional processing of positive-face distractors. Such an effect would be aptly termed a threat-disadvantage effect, but not a threat-advantage effect, because threat (in the distractors) slows down the search. Note, however, that the emotional hypothesis is also not well supported by the fact that search slopes for angry and friendly faces are highly correlated over stimuli. This result is better explained in terms of characteristics of the stimulus pair rather than only one of the stimuli (i.e., angry-face stimulus).

The present results do not show any strong evidence for a preattentive detection of negative-face targets among positive-face distractors. Is the procedure in any case biased against such a finding? I suppose that the answer is in the negative. The present experiment used a standard visual search task, which has been used earlier to reveal efficient processing (e.g., Enns & Rensink, 1990; Treisman & Gormican, 1988; Treisman & Souther, 1985). Also, more general characteristics of the task conform to the usual procedure in search experiments, such as the temporally unrestricted viewing of the display when RT is the dependent variable.

In a recent publication, Eastwood et al. (2001) argued that the search asymmetry design is biased in a different way. They correctly pointed out that in the standard search asymmetry design, effects of the target and effects of the crowd are completely confounded. An obvious solution would be to test both critical stimuli within neutral crowds. In doing so, the authors found an advantage for negative-face targets over friendly-face targets that—in their reasoning—unambiguously demonstrates better attentional guidance by the negative target faces. While the reasoning of Eastwood et al. (2001) is so far correct, it misses two important points. First, the search asymmetry design is chosen because it maximises the contrast between stimuli high on negative affect (i.e., negative faces) and stimuli low on negative affect (i.e., positive faces). If negative affect, and only negative affect, is preattentively available, we should record a classical search asymmetry. However, we do not record a classical search asymmetry, and thus we do not have to ask whether the search asymmetry is due to guidance by the target or to distractor rejection. Moreover, we have firm evidence that distractor rejection is very important for the observed effects in the target-absent trials (see also Horstmann et al., 2006b). Second, there are strong reasons to doubt that Eastwood et al. (2001) managed to circumvent the problem of possible distractor-rejection effects by using neutral crowds. In their experiment, "neutral" was equated with "affectively neutral", in that their neutral faces had a straight line as the mouth. This equation presupposes the conclusion that the effects are indeed due to the affective differences between the stimuli. However, according to Duncan & Humphreys (1989), the ease of finding the target is a function of perceptual target–distractors similarity, and it might well be that perceptual similarity between the positive-face target and the neutral-face distractors is lower than the perceptual similarity between the negative-face target and the neutral-face distractors. In fact, Horstmann et al. (2006b) demonstrated that if another "neutral" distractor is used (so called "talking heads" that result from superimposing the positive and the negative face), negative-face targets are searched for no more efficiently than positive-face targets. Also, when these neutral faces served as targets, and were searched for among either positive-face or negative-face distractors, the search asymmetry reappeared: search was relatively fast among positive-face distractors and relatively slow among negative-face distractors.

Do these results probe processes that occur outside the laboratory with natural stimuli? As far as the implications for perceptual processing are concerned there is little reason to doubt this, given that visual search is a mundane activity that most people engage in frequently every day (even as toddlers in response to their parent's question, "Where is the cat?" when viewing a picture book). As far as the implications for emotional processing are concerned, many authors, including several authors cited in this article, have assumed that emotional processes can be examined with schematic stimuli. Whether this premise is justified depends on the more specific assumption concerning the emotional processing of stimuli. As far as the attentive processing of schematic emotional stimuli is concerned, there is probably little reason to doubt that smiling and frowning schematic stimuli are viewed as emotionally laden. With respect to a specialised threat detector, however, the adequacy of schematic stimuli depends on the similarity to the original stimulus to which the detector is specialised. For example, Horstmann and Bauland (2006) detailed several differences between natural faces and some of the schematic faces used in previous experiments. Thus, at least for some schematic faces, there is reason to doubt that they excite feature detectors that are specialised for natural faces.

To summarise, the present results do not provide compelling evidence that negative facial affect is processed preattentively since the search for four out of five stimulus pairs is clearly non-efficient, and all stimulus pairs revealed a target-present to target-absent ratio of 1:2, which is indicative of serial self-terminating search. Altogether, it appears that it is time to abandon the hypothesis that affective stimulus characteristics are detected preattentively (see also Cave & Batty 2006; Wolfe & Horowitz, 2005). The present results also showed a consistent advantage for searches through happy-face rather than angry-face crowds. It is still unclear why this advantage exists. However, several facts are consistent with a perceptual account. First, perceptual differences between the stimuli within a pair exist. Second, performance in angry-face and friendly-face target-present trials correlates highly, which suggests a common underlying discrimination process.

Manuscript received 23 January 2006
Revised manuscript received 4 October 2007
Manuscript accepted 8 January 2008
First published online 24 April 2008



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