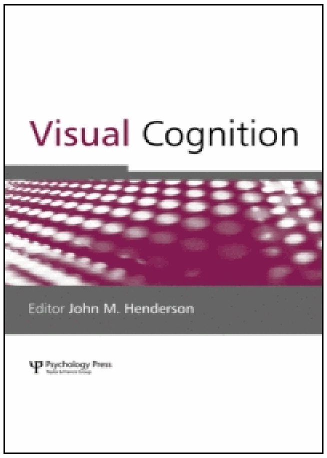

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Preattentive face processing: What do visual search experiments with schematic faces tell us?

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Preattentive face processing: What do visual search experiments with schematic faces tell us?

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In recent research, several experiments have tested a preattentive threat-advantage hypothesis that threatening or negative faces can be discriminated preattentively, by using the visual search paradigm. However, supporting evidence is nonuniform, giving rise to the suspicion that stimulus factors rather than the stimuli's category of facial threat versus friendliness are responsible for sporadic demonstrations of a threat advantage. However, it is also possible that differences in experimental procedure contribute to the heterogeneous results. To test this possibility I selected examples from the past literature and presented them within the same constant experimental setting. I found a consistent advantage for negative face targets among positive face distractors with all stimulus pairs. Search slopes, however, mostly revealed inefficient search, questioning the preattentive discrimination of facial affect.

Several theorists have suggested that affective stimulus characteristics such as its negative valence or the threat potential may be processed preattentively by specialized feature detectors (e.g., Mogg & Bradley, 1999; Öhman, 1999; but see Matthews & Wells, 1999). From an evolutionary-theoretic point of view, responding to potentially damaging stimuli quickly and without conscious preponderance is certainly of adaptive value (see also, LeDoux, 1998). It is therefore conceivable that specialized, hard-wired information processing capabilities that serve this adaptive function might have evolved. This reasoning suggests that the processing of negatively valenced social and nonsocial stimuli has primacy over, for example, the processing of positive or beneficial stimuli. This rather general expectation might be referred to as the

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threat-priority hypothesis. The hypothesis that negative or threatening facial expressions are detected preattentively can be conceived of as a specific version of this hypothesis. The present paper is concerned with this *preattentive threat-detection hypothesis*.

The visual search paradigm is the most important tool to test claims about preattentive access to stimulus features. This paradigm tests whether a stimulus' feature is available for information processing independently of the current focus of visuospatial attention (i.e., preattentively). Typically, the task is to find a target among distractors (e.g., Treisman & Gelade, 1980; Wolfe, 1998, 2001). If the target has a perceptual feature that can be detected before its attentional processing is initiated, it can be found efficiently, with detection latency being independent of *set size*, which is the number of totally presented stimuli. For example, if an angry face is found with a latency of 500 ms, when presented among 10, 20, or even 30 happy faces, search is efficient by definition and some feature of the angry face is assumed to be accessible before attention is directed to it (in fact, it can be used to guide attention to its location). In contrast, if the latency of finding a stimulus is positively related to set size, it is assumed that the detection of the stimulus is the result of the serial deployment of focal attention on the stimuli in succession until the target is detected (note that throughout the paper, I refer to covert shifts of attention that need not coincide with overt shifts, i.e., eye movements; cf. Posner, Synder, & Davidson, 1980). For example, if the finding of a friendly face among 10, 20, and 30 angry faces lasts 500 ms, 1000 ms, and 1500 ms, respectively, search is nonefficient by definition, and the detection of the presence of the friendly face would be assumed to follow attention rather than precede it.

Search efficiency is mathematically defined as the slope b of the linear function $y = bx + a$ that relates finding latency (y) to set size (x). Slopes near 0 ms can be labelled as very efficient, around 5–10 ms as quite efficient, around 20–30 ms as inefficient, and over 30 ms as very inefficient[1] (Wolfe, 1998). Efficient search is evidence for preattentive access although converging operations have to strengthen the case (Wolfe & Horowitz, 2004). The criteria for efficient search vary to some degree (e.g., testing the slope statistically against zero), but slopes of more than 10 ms are normally not considered as compelling evidence for preattentive processing.

In theory (e.g., Treisman & Gelade, 1980; Wolfe, 1994), nonefficient search is often due to the fact that target and distractors share basic features

[1] A strict distinction between efficient and nonefficient processes (e.g., Treisman & Souther, 1985) has been convincingly criticized (cf. Wolfe, 1998), because search functions show a continuum of slopes, not a dichotomy. However, this critique does not imply that efficient search is not a necessary criterion for preattentive processing; it just says that it is not sufficient, because serial search can also be very efficient (e.g., Wolfe & Horowitz, 2004).

(e.g., horizontal or vertical lines in the letters T and L), and that the specific conjunction of these features defines their identity as target or distractors. A specific conjunction of basic features, in turn, normally requires attention to be detected (e.g., Treisman & Gelade, 1980; although there is evidence that new basic features can be acquired through practice, cf. Schyns, Goldstone, & Thibaut, 1998). Initially it was thought that search for basic features is always efficient and that conjunction search is always inefficient (e.g., Treisman & Souther, 1985), but it turned out that some conjunction searches are also very efficient, which led to modifications of the original theory (e.g., Guided Search 2.0; Wolfe, 1994). Thus, efficient search is held to be a necessary, but not a sufficient criterion for preattentive processing (Wolfe & Horowitz, 2004).

A particular variant strategy that makes use of the visual search paradigm is the examination of search asymmetries as a "diagnostic for preattentive processing of separable features" (e.g., Treisman & Gormican, 1988; Treisman & Souther, 1985; Wolfe, 2001). A search asymmetry amounts to the finding that depending on which of two types of stimuli is used as the target versus distractor, either pop-out or serial search results. For example, a search asymmetry would be revealed if search for an angry among happy faces is efficient, whereas search for a happy among angry faces is inefficient. A search asymmetry is considered an important diagnostic of a preattentively available basic feature (Wolfe & Horowitz, 2004). It would indicate that the two stimuli can be compared on a preattentively available feature that is present in the angry face but missing in the happy face (e.g., Treisman & Souther, 1985), or that is present in large quantities in the angry face but in little quantities by the happy face (Treisman & Gormican, 1988).

The search asymmetry design has been applied to test whether facial threat is a preattentively available stimulus dimension. The respective studies have compared search efficiency for an angry-face target (being negative or threatening; e.g., Horstmann, 2003) in a happy-face crowd to the search efficiency for a happy-face target in an angry-face crowd. Clearly, an angry face would be characterized by high quantities of facial threat, whereas a friendly face would be characterized by very low quantities of facial threat. According to the logic of search asymmetry designs (cf. Wolfe, 2001), the finding of pop-out of an angry face target in a friendly face crowd but of slow serial search for a friendly face target in an angry face crowd would be evidence for a preattentive facial-threat analyser, but no facial-friendliness analyser, as predicted by the threat-advantage hypothesis. For the sake of clarity, if—contrary to the threat-advantage hypothesis—there were a second preattentive facial-friendliness analyser, no search asymmetry but efficient searches with both targets would be obtained. Finally, nonefficient searches for both threatening and friendly target faces would suggest that facial valence is not preattentively available, but that faces must be processed attentively to extract their valence or social meaning. Thus, finding a search asymmetry would be a necessary condition for the claim that avoidance related affect (threatening or negative) is a preattentively available dimension, whereas approach related affect is not.

In the following, the pertinent findings bearing on the issue of preattentively available threat or negative valence information will be reviewed. I will argue that the evidence for a preattentive identification of facial threat in studies using the search asymmetry diagnostic is mixed, posing questions about stimulus and method factors.

LITERATURE REVIEW

A number of experiments, using different methods, have examined the hypothesized preattentive processing of facial affect (e.g., Eastwood Smilek, & Merikle, 2001; Fenske & Eastwood, 2003; Fox et al., 2000; Hansen & Hansen, 1988; Horstmann & Bauland, 2006; Horstmann, Borgstedt & Heumann, 2006; Horstmann, Scharlau & Ansorge, in press; Nothdurft, 1993; Öhman, Lundqvist, & Esteves, 2001; Schubö, Gendolla, Meinecke, & Able, in press; Tipples, Atkinson, & Young, 2002; White, 1995; Williams, Moss, Bradshaw, & Mattingley, 2005; for a short overview of the different paradigms and the typical results see Horstmann et al., 2006). The present paper focuses on experiments with the search asymmetry design, which has been used most extensively, and which tests the preattenitve threat-advantage hypothesis most directly. In addition to these, there are a number of visual search studies on facial expressions that did not vary set size and thus cannot answer the question of preattentive processing (e.g., Tipples et al., 2002); in short, these studies consistently reveal shorter response latencies to angry or negative faces. A few other visual search studies tested positive and negative faces within neutral crowds (e.g., Eastwood et al., 2001; Williams et al., 2005). Their virtues and problems are discussed in the General Discussion.

The present work is concerned with studies that presented schematic stimuli. Schematic stimuli have been chosen most frequently after critical examinations of the original study by Hansen and Hansen (1988) fostered doubts on the generality of the reported threat-advantage for photographic stimuli (Purcell, Stewart, & Skov, 1996). Schematic faces are often considered as better suited for a test of the threat-advantage hypothesis than photographic stimuli, because of the excellent experimental control over the contrasting features (e.g., Öhman et al., 2001), and some authors have explicitly assumed that their stimuli excite an evolved facial-threat detector (Öhman et al., 2001). Thus, although concerns about the ecological validity of these stimuli can be raised (e.g., Horstmann & Bauland, 2006;

Horstmann et al., 2006), the results obtained with these stimuli are a centrepiece in an argument for the preattentive threat-advantage hypothesis.

In the following, we will first take a short look on search asymmetry experiments with photographic stimuli, followed by the main part on schematic stimuli. Within this division, the review is chronologically organized. It begins with Hansen and Hansen (1988) and Horstmann and Bauland (2006) on photographic faces, followed by Nothdurft (1993), White (1995), Fox et al. (2000), Öhman et al. (2001), and Horstmann et al. (in press), on schematic faces.

Studies with photographic stimuli

Hansen and Hansen (1988), Exp. 3) were the first to conduct a visual search study with the aim of testing a possible preattentive threat-advantage for angry faces. They presented angry faces in happy crowds and happy faces in angry crowds with varying set sizes of four and nine faces. The faces were digitized and contrast-enhanced photographs from the Ekman and Friesen (1976) set of facial expressions of emotion (see also the publication of Purcell et al., 1996, for reproductions of the stimuli used in Hansen & Hansen). Photos of two stimulus persons were used in the experiments, but each participant saw the face of only one stimulus person. In half the trials (target absent trials), no target was presented, with angry and happy crowds being presented equally often. In the remaining trials (target present trials), a happy face or an angry face was presented in a crowd of the other facial expression. The participant's task was to indicate the presence of a discrepant face with a keypress. Hansen and Hansen obtained a classic search asymmetry with a slope of 8 ms/face with an angry target but a slope of 52 ms/face with a happy target. Hansen and Hansen's use of photographic stimuli has been proven to be problematic. In particular, Purcell et al. (1996) substantiated that the original results are due to a confound that occurred during the digital image processing, resulting in conspicuous black spots that pertained only to the angry faces and not to the happy faces. Apparently, the participants detected this confound and used it to discriminate between target present and target absent trials with happy crowds. In the replication of Purcell et al., only those participants who reported the confound also revealed efficient search for angry target faces. Moreover, when the original greyscale pictures were used instead of the digitally processed high contrast derivates, the search asymmetry was not obtained.

Because of these problems, almost all subsequent visual search studies presented schematic faces. Horstmann and Bauland (2006) argued that this might have been an overreaction. They pointed out that a perceptual confound with facial expression is a difference between faces that is unrelated to the difference in expression. Artifacts, defined in this way, are not too difficult to eliminate. Horstmann and Bauland tested two pairs of faces (happy vs. angry) in a search asymmetry design. They found nonefficient searches for both pairs, but also a search inequality, that is more efficient search for the angry face target among the happy face distractors (11 ms/item) than vice versa (17 ms/item). (I will henceforth use the term *search inequality* to indicate that search slopes are different for two types of stimuli but do not show a search asymmetry proper as defined before.) Further experiments found that the mouth region alone, but not the eyes region, was important for the search inequality (4 vs. 8 ms/item for the angry vs. happy mouth, respectively; 54 ms/item for both angry and happy eyes). Finally, virtually the same search inequality was found for upright and inverted Thatcherized (cf. Thompson, 1980) versions of the stimulus pair, which was taken as evidence that perceptual rather than emotional factors were responsible for the search inequality. Horstmann and Bauland (2006) interpreted their results to be in line with a sensory-bias hypothesis that important social signals like facial threat developed in human evolution such as to exploit extant capabilities of the visual system to the effect of their relative salience and conspicuousness.

Studies with schematic stimuli

Nothdurft (1993, Study 5). Nothdurft (1993) conducted a series of studies to test the possibility of preattentive discrimination of facial affect. His stimuli were based on a circle, with dots as eyes, a "^" as a nose, and a curved line as the mouth as facial components. Unlike in the other studies, the heads were covered with hair. Set sizes were large with up to 57 items. The displays were visible until a response occurred. In the critical Series 5, where smiling faces in frowning crowds or vice versa were shown, three set sizes were used with 4, 20, and 48 items (based on the information presented in Nothdurft, 1993, Figure 3b.). The task was to indicate the presence of a prespecified happy or angry target. The results revealed inefficient search with a slope of 61.7 ms/item and no search asymmetry.

White (1995, Exp. 1). White's (1995) faces were composed of a circle as the face's outline, a stroke as the nose, and small circles as eyes (see Figure 1). The stimuli were presented on the circumference of an imaginary circle, that is, equidistantly from fixation, using set sizes of two, four, or six stimuli. The task was to indicate whether the display contains a discrepant face. The stimuli were presented for 500 ms. The experiment revealed practically flat search functions for target present trials; target absent slopes were about 40 ms/item. Thus, White found 0 ms slopes for happy and for sad faces but no search asymmetry.

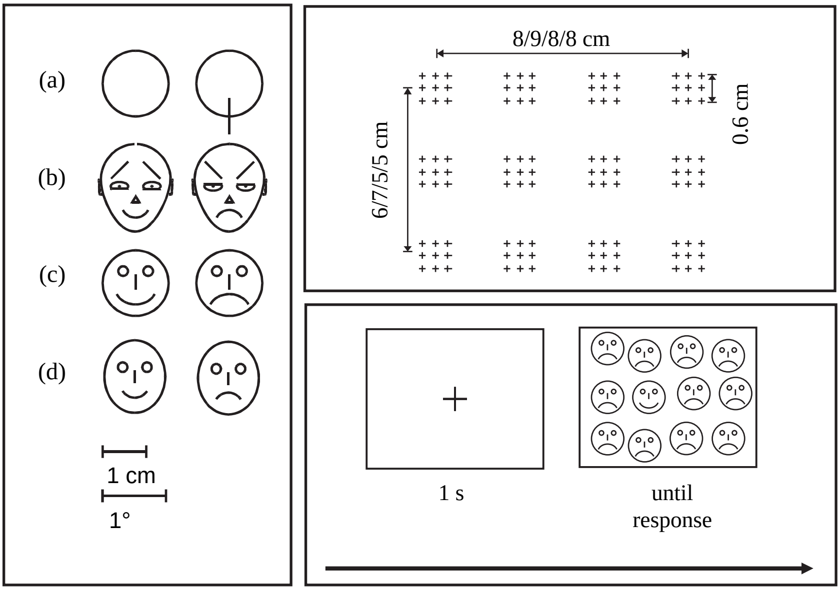

Figure 1. Overview over the stimuli used in the present experiments. Left: The stimuli were intended to be replicas of the (a) stimuli of Treisman and Souther (1985), Exp. 1), (b) Öhman et al. (2001), Exp. 3), (c) White (1995), and (d) Fox et al. (2000), Exp. 5). Right top: Each cross indicates a possible position for a stimulus (note that within a nine-cross block, only one stimulus could appear). Right bottom: Sequence of events within a trial.

Fox et al. (2000, Exp. 5). Fox et al. (2000) presented schematic faces that were similar to those of White (1995) except that the outline was an oval (see Figure 1). In some of the experiments brows made the negative face look more unambiguously angry than sad, but the brows were omitted in the only experiment in which set size was varied (four vs. eight). The displays were circular and the task was to find the discrepant face. The displays were presented for 800 ms. The authors found shallower search slopes for angry (16 ms) than for happy targets (29 ms). A threat advantage was also evident in the error rates, which did not increase with set size for angry faces but did with happy faces as targets. Thus, search was not spatially parallel for negative targets, but more efficient than for positive targets.

Öhman et al. (2001, Exp. 3). This study presented the most elaborate schematic facial expressions (see Figure 1). In particular, the faces were constructed such that when the orientation of the eyes, mouth, and brows in happy faces was considered as a 0°, each of these features had a 180° orientation in the angry face. Set sizes of 4, 9, and 16 faces were used, with faces arranged in regular matrices. The stimuli were presented until a response was registered. The task was to indicate the presence versus absence of a discrepant face. Öhman et al. (2001) did not find a search asymmetry but relatively inefficient search for both angry and happy target faces, with search slopes of approximately 35 ms/face in the target present trials and about 75 ms/face in the target absent files (the latter value is derived from Figure 5 of Öhman et al.). While search was clearly inefficient for both targets, it is possible that a speed–accuracy tradeoff masked a search asymmetry, because the error rates revealed a set size effect with angry crowds and friendly targets, but not in the reversed condition.[2]

Horstmann, Scharlau, and Ansorge (in press, Exps. 1a and 2a). This study presented schematic faces made up of a circle, two dots, and a curved line, similar to the popular "smilies" first used in the present context by Eastwood et al. (2001). The stimuli were presented in an irregular 3×4 matrix. Set sizes were 1, 6, and 12. The task was to find a prespecified target, which was constant for a block of trials. The stimuli were visible until a response occurred. A negative-face target in a positive-face crowd was found more efficiently (6 ms/item and 12 ms/item, in Exps. 1a and 2a respectively) than a positive-face target in a negative-face crowd (15ms/item, and 26 ms/item). Thus, the angry-face target present slopes were in the vicinity of efficient processing, and there was a search inequality, but no classical search asymmetry with a clearly flat slope for the angry-face target and a clearly steep slope for the happy face target.

RATIONALE AND OVERVIEW OF THE PRESENT EXPERIMENTS

The review reveals rather heterogeneous results from the existing studies. The target present slopes ranged between 0 ms (White, 1995) and 62 ms (Nothdurft, 1993), and some studies found a search inequality favouring negative faces, whereas others did not, but no study obtained a classical

[2] Öhman et al. also obtained a crowd effect, with responses to happy crowds being faster and error rates being lower, at least for target present trials (Öhman et al. did not report the results for target absent trials separately for angry and happy crowds). For the sake of clarity, it should be emphasized that with a visual search paradigm, a crowd effect is not indicative of search efficiency: It is the slope (b) of the function relating RT to set size ($y = bx + a$) that reveals preattentive processing versus serial search, not the intercept term (a) of the function. Rather, the intercept reveals processes that occur before the beginning of the search or between the termination of the search and the production of the response, but not during search. For example, faster RTs to positive crowds may reveal less hesitation in beginning with the scanning of the positive crowd, a longer time in deciding that really no discrepant face is present for negative crowds, or a slower response execution with negative crowds. Either of these effects may be due to genuinely affective or to purely perceptual factors.

search asymmetry. Certainly, flat or nearly flat search functions for negative target faces obtained in one study (e.g., Horstmann et al., in press, Exp. 1a; White, 1995) cannot be taken as evidence for the preattentive discrimination of facial affect, when other studies found considerably steep search functions (e.g., Öhman et al., 2001). Moreover, because all studies used different facial stimuli, it appears that search slopes varied as much within as between the categories of threat (or negative valence) and friendliness (or positive valence). This lack of categorical perception is contrary to what one expects if the effects are due to an underlying dimension of threat or negative valence. It rather indicates that search efficiency depends on the particular layout of the stimuli used as targets and as distractors.

One possible response, in an attempt to save the preattentive threat-detection hypothesis, is that the results cannot be directly compared, because the experiments differed not only in the stimuli but in procedural details as well. For example, some studies presented the stimuli in matrices, while others used circular displays, displays were regularly or irregularly filled, the size of the stimuli varied, as well as their density, the size of the display, the choice of set sizes, display durations, and so on. It is thus unclear as to which factor (stimulus factors or procedural details) the differences in search slopes are causally related.

In order to control for—in fact to eliminate—differences in procedural details, I decided to set up a standard procedure, and to test different stimulus pairs from the literature within this fixed frame. This allows for a direct comparison of the stimuli and thus for a test of the conjecture that the results pattern varies with the particular stimulus pair rather than with the category of facial expressions of emotion. Moreover, in order to test the validity of the method, an additional experiment was run using nonfacial stimuli that show a search asymmetry (Treisman & Souther, 1985). This provides a calibration of the method, and a reference for the later experiments with regard to efficient and nonefficient search.

The facial stimuli used were constructed to be similar to those of Öhman et al. (2001), Fox et al. (2000), and White (1995). Horstmann et al. (in press) have already used exactly the present design, so their results can be directly compared to the present experiments. Only schematic stimuli were tested, because these were the stimuli presented in the quoted studies.

GENERAL METHOD

Experiments 1–4 were conducted in the same laboratory cubicle using the same equipment. This was a PC equipped with a 80486 CPU, connected to a colour monitor (screen 32×24 cm; viewing distance was 80 cm) run with a resolution of 1024×768 pixels for stimulus presentations, and to a keyboard used to collect the manual responses. Stimulus presentation was white on black.

The basic design was closely modelled on one frequently used in visual search experiments (e.g., Enns & Rensink, 1990; Treisman & Gormican; 1988; Treisman & Souther, 1985). Participants completed two blocks of trials. In each block, they were presented with display sizes of 1, 6, and 12 facial stimuli. Blocks 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 $\times$ target identity $\times$ target presence was repeated 25 times. Dependent variables were RT and error proportions. Block order was balanced, as was the stimulus–response mapping (i.e., half of the participants responded with the left response key when the target was present and with the right response key when the target was absent, while for the other half this mapping was reversed).

In each trial, 1, 6, or 12 facial stimuli (see Figure 1) were presented inside a monitor area of about 8 cm $\times$ 5 cm (the dimensions varied slightly between experiments, to prevent adjacent stimuli from overlapping). 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. This procedure resulted in a moderately irregular arrangement of the stimuli, intended to eliminate possible suprastimulus cues to the target's position (Duncan & Humphreys, 1989). The sequence of conditions within a block was randomized.

Participants were fully informed about their task and the structure of the experiment by written and oral instructions. Before each main block, the identity of the target in the following trials was announced on the screen. For example, participants were told that they should search for the happy 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 face display was on until a response was made. A trial was aborted if no response was made within 6 s. 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 cutoff concerned less than 1% of the trials). Mean reaction times for each of the 12 experimental conditions were calculated. Because the predictions for preattentive processing concerns the slopes of the RT–set size functions, separate linear regressions with RT as the dependent variable and set size as the independent variable were computed for each of the 2 (target presence: Present vs. absent) $\times$ 2 (target identity: Happy vs. angry) conditions, separately for each participant, to obtain individual estimates of the two parameters b (slope) and a (intercept). Further analysis was done using the regression parameters. For the analysis of the errors, error scores were computed as the proportion of false responses. Analogously to the RT analysis, the statistical tests were performed on the slope and intercept parameters.

Predictions

The preattentive threat-advantage hypothesis predicts that the target present slope for angry targets is near zero, that is, search is efficient. This is tested by using a comparably lenient criterion that a slope of less than 10 ms/stimulus is reasonably flat to indicate efficient search (e.g., Wolfe, 1998). Second, the preattentive threat-advantage hypothesis, which furthermore assumes that *only* avoidance-related, but not approach-related information can be used to guide attention, additionally predicts a classical search asymmetry, that is efficient search for the avoidance-related target among approach-related distractors, but inefficient search for the approach-related target among avoidance related distractors. This prediction assumes at least (i.e., as a necessary but not a sufficient condition) a search inequality, with steeper slopes for approach-related targets than with avoidance-related targets. Third, as stimulus differences are deconfounded from procedural differences, more convergence between the present experiments is expected than that observed in previous studies. In particular, assuming that all stimulus pairs test the same hypothesis of a preattentively available threat/negative valence dimension, we expect converging evidence for efficient search for angry/negative faces. Fourth, if stimulus factors are important for the results, we expect differences in search efficiency depending on the particular stimulus pair tested.

EXPERIMENT 1

Experiment 1 was a conceptual replication of Experiment 1 by Treisman and Souther (1985), in which circles and "lollipops" (i.e., a circle with a vertical line intersecting at 180°; see Figure 1a) were presented. The experiment was intended to "calibrate" the currently used experimental set up (i.e., to ensure that pop-out and search asymmetries would actually be established with the present set up).

Method

Participants. Eight students from Bielefeld University, one man and seven women, with a mean age of 24 years ($SD = 3.3$), participated. Here and in the following experiments, participants volunteered in exchange for €3 or in part fulfilment of study requirements.

Stimuli. Stimuli are depicted in Figure 1. Technically, the bitmap containing the stimuli were such that the circles were located at the same position within the bitmap for both stimuli. Average adjacent positions were separated by 2.7 cm horizontally and 3 cm vertically (measured from the centres of the stimuli).

Results

Slopes. Figure 2 shows the grand means for RTs and errors of Experiment 1. Table 1 summarizes the results of the ANOVAs for the present and the following experiments, Table 2 reports the mean slopes and intercepts. The ANOVA of the slopes for RTs revealed significant main effects for target presence, revealing shallower slopes for target present than for target absent trials (11 vs. 23 ms/item), and target identity, revealing shallower slopes for lollipops than circles (2 vs. 32 ms) and a significant Target presence × Target identity interaction, indicating a substantial effect for target presence with the circles, but not with the lollipops (see Table 1). A corresponding ANOVA of the slopes for errors proportions revealed no significant effects.

The predicted search asymmetry was revealed by a one-tailed t-test for the difference between the lollipop versus circle target present trials, $t(7) = 8.6$, $p < .001$. Lollipops were detected efficiently within circles with a mean slope of 3 ms/item, whereas circles were detected with a much slower scanning rate of 19 ms/item.

Intercepts. The ANOVA of the intercepts for RTs revealed a significant main effect for target identity only, revealing faster RT with the lollipop target than with the circle target (499 vs. 545 ms). The ANOVA of the error intercepts revealed no significant results.

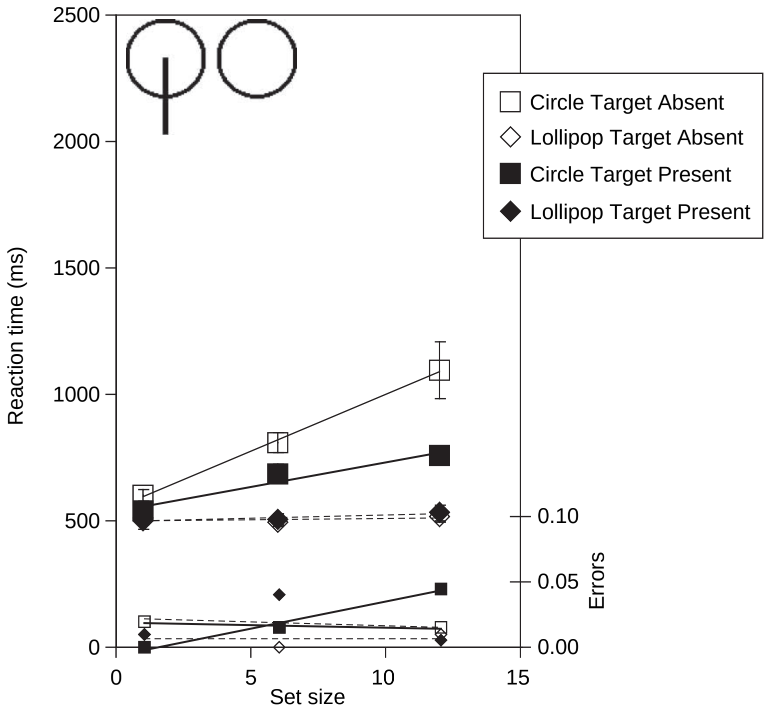

Figure 2. Mean correct RTs and error rates for each of the 12 conditions in Experiment 1. Filled symbols represent target present trials and unfilled symbols target absent trials. Diamond code for trials with a lollipop target; square code for trials with a circle target. The figure also displays the linear trends obtained by linear regression analysis.

Discussion

The results were very similar to those obtained by Treisman and Souther (1985), with efficient search for the lollipop target in both the target present and the target absent trials, but inefficient search for the circle target among lollipop distractors, and a large difference in the slopes between target present and target absent trials. Treisman and Souther (see also Treisman & Gormican, 1988) explain this result by assuming that the lollipop possess a basic feature (e.g., "vertical") lacking in the circle. For this reason, in circle-crowd trials, participants can compare and discriminate the activation in the corresponding basic feature map, indicate target absent if no activation is detectable, and target present if there is some activation in the feature map. In contrast, in lollipop-crowd trials, the activation in the feature map is strong in both target present and target absent trials, with the difference too small to permit detection. For this reason, participants have to engage in a serial self-terminating search for the circle. The most important result,

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, in Experiments 1–4

	Slope		*Intercept*	
	RT	*Errors*	*RT*	*Errors*
Experiment 1 (Treisman & Souther, 1985, Exp. 1)				
Presence	**6.18**	2.03	0.46	3.15
Crowd	**38.27**	2.03	**8.79**	1.05
Presence*Crowd	**9.97**	2.03	0.07	3.13
Experiment 2 (Öhman et al., 2001, Exp. 3)				
Presence	**26.62**	1.84	2.63	1.31
Crowd	3.28	0.30	1.71	0.56
Presence*Crowd	0.84	0.30	0.29	0.50
Experiment 3 (White, 1995)				
Presence	**24.30**	**5.65**	0.05	**9.00**
Crowd	**34.89**	4.20	**5.56**	3.76
Presence*Crowd	3.16	0.30	0.45	2.87
Experiment 4 (Fox et al., 2000, Exp. 5)				
Presence	**38.32**	**8.76**	0.11	0.06
Crowd	**23.90**	1.34	0.00	2.48
Presence*Crowd	0.01	0.12	0.04	1.26
Experiment 5 (White, 1995, inverted)				
Presence	**80.31**	1.0	**9.69**	0.04
Crowd	**10.63**	2.03	0.56	2.35
Presence*Crowd	1.45	0.18	0.03	0.02

For all Fs, nominator *df* were 1 and denominator *df* were 7; Bold values exceed the critical $F = 5.56$, $p = .05$.

however, is that the present experimental set-up is apt to test efficient search and search asymmetries.

There was also an intercept effect for target identity, revealing quicker responses to lollipop targets than to circle targets. It is interesting to note the presence of this effect, because with angry and friendly faces, an analogous intercept effect has also been found (analogous in the sense that the target for which more efficient search is predicted also has a lower intercept). However, intercept effects in visual search are highly ambiguous and usually considered irrelevant as to the question of preattentive processing.

EXPERIMENT 2

Experiment 2 presented stimuli similar to those used by Öhman et al. (2001); see Figure 1). As in all the following experiments, only positive and negative

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

	Slope		*Intercept*	
	RT	*Errors*	*RT*	*Errors*
Experiment 1 (Treisman & Souther, 1985, Exp. 1)				
CTP	19.4	0.004	539	–0.008
LTP	2.8	0.000	495	0.020
CTA	44.8	0.000	552	0.020
LTA	0.8	0.000	502	0.008
Experiment 2 (Öhman et al., 2001, Exp. 3)				
FTP	45.6	0.004	679	0.021
ATP	31.5	0.003	648	0.018
FTA	95.1	0.000	732	0.004
ATA	87.2	0.000	685	0.004
Experiment 3 (White, 1995)				
FTP	36.5	0.004	571	0.005
ATP	12.5	0.001	641	0.010
FTA	72.1	0.000	583	0.000
ATA	36.9	–0.001	636	0.030
Experiment 4 (Fox et al., 2000, Exp. 5)				
FTP	64.9	0.005	632	0.009
ATP	32.1	0.003	633	0.014
FTA	111.8	0.000	629	–0.001
ATA	79.9	–0.001	623	0.020
Experiment 5 (White, 1995, in*v*erted)				
FTP	34.9	0.000	708.6	0.038
ATP	13.3	0.001	669.8	0.016
FTA	84.2	–0.003	745.1	0.041
ATA	52.1	0.000	697.3	0.018

CTP = circle target present; LTP = lollipop target present; CTA = circle target absent; LTA = lollipop target absent; FTP = friendly target present; ATP = angry target present; FTA = friendly target absent; ATA = angry target absent.

faces were used. The average distance between adjacent positions was 3 cm horizontally and 3.5 cm vertically.

Method

Participants. Eight students from Bielefeld University, one man and seven women, with a mean age of 24 years ($SD = 3.0$), were able to perform at an acceptable error rate (no more than 20% errors in any one of the 12 experimental conditions, and no more than 10% errors on average).[3] Three additional participants failed to meet the criterion and were not included in the reported analyses. It might be noted that the conditions with high error rates were not randomly distributed; rather they were typically in the set size 12/target present condition. High error rates in large set size/target present conditions, indicating a lot of "misses" according to signal detection theory, are not rare in visual search experiments (see, for example, Treisman & Souther, 1985). However, I wanted the set size effect to register in the RTs and not in the error rates, and high error rates compromise the interpretation of the RTs because of a speed–accuracy tradeoff. Note however, that the exclusion of participants with high error rates was done exclusively to facilitate the interpretation of the RT; an inclusion of the participants in the analysis does not alter the results patterns reported below in any important way.

Results

Slopes. Figure 3 shows the means for RTs and errors of Experiment 2. The ANOVA of the slopes for RTs (see also Tables 1 and 2) revealed a significant main effect for target presence only, reflecting shallower slopes for target present than for target absent trials (39 vs. 91 ms/item). A corresponding ANOVA of the slopes for errors revealed no significant effects.

The predicted search inequality was confirmed by a one-tailed t-test for the RT slope difference between the angry versus happy target present trials, $t(7) = 1.9$, $p = .05$. Angry faces were detected more efficiently than happy faces (32 vs. 46 ms/item).

Intercepts. The ANOVA of the intercepts revealed no significant effects (see Table 1).

Discussion

The experiment did not reveal efficient processing for angry or happy faces, roughly replicating the results from Öhman et al. (2001). The present-to-

[3] Initially, we chose this rather stringent exclusion criterion because we feared that speed–accuracy tradeoffs that are specific for certain conditions would level out differences in RTs between these conditions. Later it turned out that the exclusion did barely change the patterning of the RTs. However, because the experimental design assumes that method factors (order of conditions and response mapping) are balanced across participants, we present the data as we originally collected them.

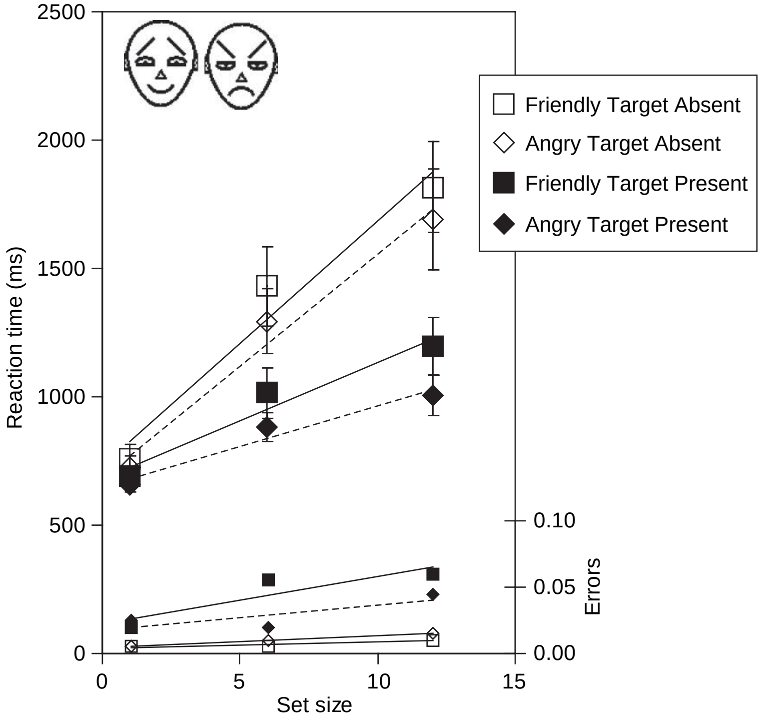

Figure 3. Mean correct RTs and error rates for each of the 12 conditions in Experiment 2. See also Figure 2.

absent slope ratio was approximately 1:2, indicating a serial self-terminating search. In contrast to Öhman et al., however, search was somewhat more efficient for angry faces than for happy faces. Öhman et al. probably did not find the search slope difference because (a) the minimal set size they used was four items and (b) the slope is not constant in the ranges of 1–6 and 6–12, but steeper with the smaller set sizes (see Figure 2). Accordingly, the set sizes used by Öhman et al. may have underestimated the slope of the search function. This interpretation is fostered by the fact that the intercept effect found by Öhman et al. is absent in the present experiment, which is consistent with the proposed account, if one assumes that the underestimation of the slope was more pronounced with the happy faces. (One may argue that the present experiment overestimates the slopes by the use of set size 1; a control experiment that used two faces as the minimal set, however, rendered practically the same slopes as a corresponding experiment with one face as the minimal set size; see Methodological Controls section).

EXPERIMENT 3

Experiment 3 presented stimuli (see Figure 1) similar to those used by White (1995). The distance between adjacent positions was 2.7 cm horizontally and 2.5 cm vertically (as measured from the centre of the stimuli).

Method

Participants. Eight students from Bielefeld University, one man and seven women, with a mean age of 24 years ($SD = 1.4$), participated; two additional participants had more than 20% errors in at least one of the 12 experimental conditions, and were thus excluded from further analysis.

Results

Slopes. Figure 4 shows the means for RTs and errors of Experiment 3. The ANOVA of the slopes for RTs (see also Tables 1 and 2) revealed a

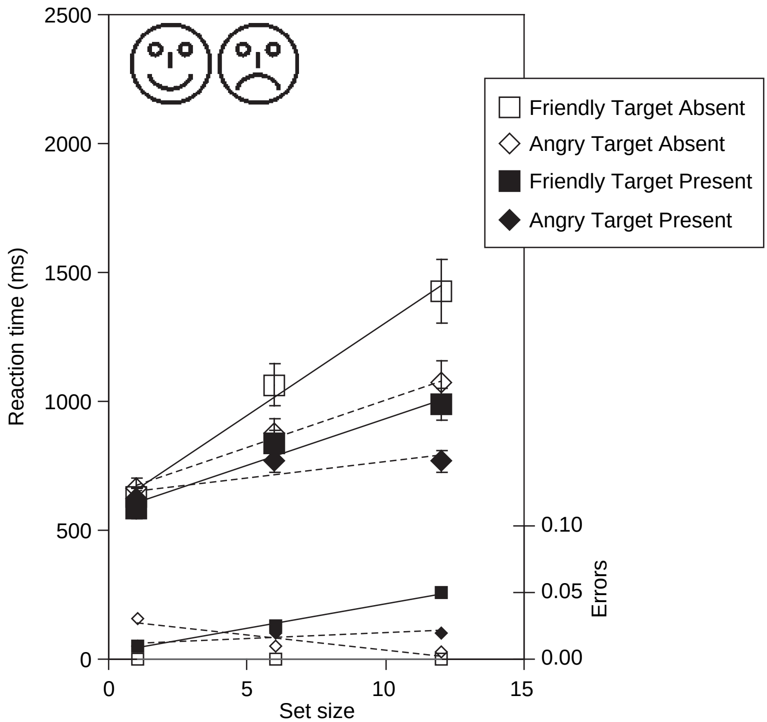

Figure 4. Mean correct RTs and error rates for each of the 12 conditions in Experiment 3. See also Figure 2.

significant main effect for target presence, indicating shallower slopes for target present than for target absent trials (24 vs. 55 ms/item), and a significant main effect for target identity, indicating that slopes were less steep when the target was an angry face versus a happy face (25 vs. 54 ms/item). A corresponding ANOVA of the slopes for errors also revealed significant main effects for target presence and target identity: Errors depended more on set size in target present trials (0.3% errors/item) than in target absent trials (-0.1% errors/item), and errors were more dependent on set size with happy than angry targets (0.1 vs. 0.2% errors/item).

A search inequality was confirmed, $t(7) = 7.1$, $p < .001$, with angry faces being detected more efficiently than happy faces (13 vs. 36 ms/item).

Intercepts. The ANOVA of the intercepts for RTs revealed a significant main effect for target identity, revealing longer RTs for the angry than the happy faces (639 vs. 577 ms). The corresponding ANOVA for errors-intercepts revealed a significant main effect for target presence, with errors being much more frequent in target present trials than in target absent trials (1.5% vs. 0.8% errors).

Discussion

Experiment 3 revealed no efficient processing for angry or happy faces, although the slope for the angry target present trials was quite shallow (12.5 ms/item). The search inequality was pronounced, with an advantage for the angry relative to the happy faces. The qualitative pattern of results is similar as in Experiment 2, although the effect is much stronger in the present experiment.

The results did not replicate White (1995). White found no search asymmetry or inequality but rather efficient search for both angry and happy faces. It is unclear where the discrepancies originate as there are many procedural differences between the two experiments. Note that the possibility of variance introduced by different procedural details apart from the stimuli was exactly the reason to conduct the present study, and the discrepancies obtained reveal the importance of this endeavour. While the discrepancies introduced by the procedures have to be clarified by further research, the present approach allows the comparison of search efficiency for different stimulus pairs, without possibly confounding procedural differences.

EXPERIMENT 4

Experiment 4 presented stimuli (see Figure 1) very similar to those used by Fox et al. (2000). The distance between stimuli was the same as in Experiment 3.

Method

Participants. Eight students from Bielefeld University, two men and six women, with a mean age of 24 years ($SD = 2.7$), participated; an additional participant had more than 20% errors in at least one of the 12 experimental conditions, and was thus excluded from further analysis.

Results

Slopes. Figure 5 shows the means for RTs and errors of Experiment 4. The ANOVA of the slopes for RTs (see also Tables 1 and 2) revealed a

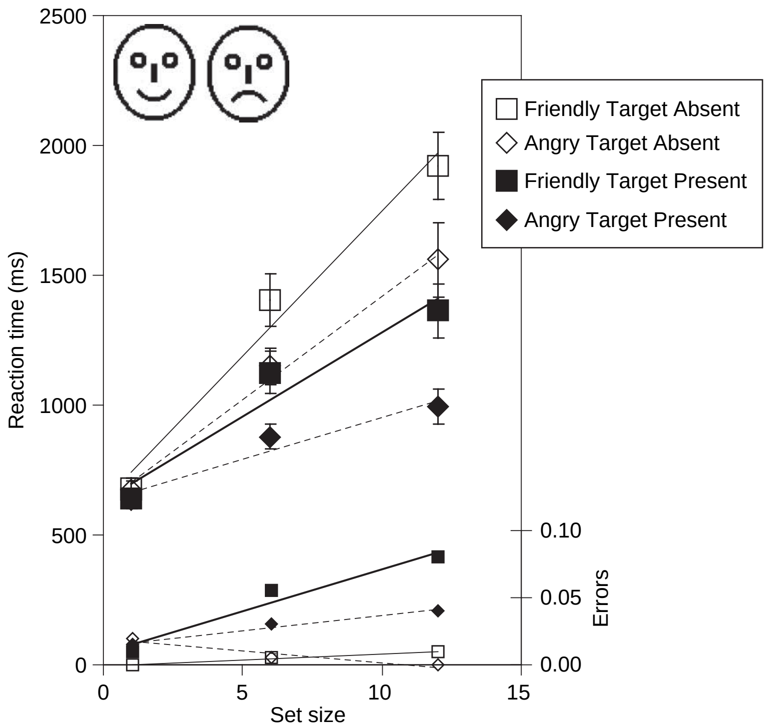

Figure 5. Mean correct RTs and error rates for each of the 12 conditions in Experiment 4. See also Figure 2.

significant main effect for target presence, revealing shallower slopes for target present than for target absent trials (48 vs. 96 ms/item), and a significant main effect for target identity, indicating that slopes were less steep when the target was an angry face (56 vs. 88 ms/item). A corresponding ANOVA of the slopes for errors also revealed a significant main effect for target presence: Errors depended more on set size in target present trials (0.4% errors/item) than in target absent trials (–0.1% errors/item).

The predicted search inequality was revealed by a one-tailed t-test for the RT slope difference between the angry versus happy target present trials, $t(7) = 6.1$, $p < .001$. Angry faces were detected more efficiently than happy faces (32 vs. 65 ms/item).

Intercepts. The ANOVAs of the intercepts revealed no significant main effect (see Table 2).

Discussion

Experiment 4 did not support the assumption of preattentive discrimination of happy versus angry faces, because the target present slopes were rather steep. Moreover, the present-to-absent ratio is about 1:2 with each of the two targets, indicating serial self-terminating search. However, similarly to Experiments 2 and 3, a search inequality was revealed, with considerably faster detection of the angry target. When comparing the results to the experiment by Fox et al. (2000), the results patterns show similarities and differences. The results of both experiments are similar to the extent that a search asymmetry was also found by Fox et al. However, the search slopes in the present experiment were higher than in the original study, in particular the target present slopes (see introduction). Repeating what was said in the Discussion section of Experiment 3, the concerns about procedural differences between the studies are confirmed, as is the importance of replicating apparently discrepant results from different paradigms.

Methodological controls

Two methodological concerns should be shortly examined. First, the present experiments used a consistent mapping procedure, where the same target was used in all trials of a block, whereas an inconsistent mapping procedure has been used in some of the preceding experiments, where the target in trial $N - 1$ could be the distractor in trial N. It is probable that the two tasks impose slightly different demands on the observer. To test this empirically, I ran a control experiment (eight participants) very closely corresponding to Experiment 3, but with the requirement to report whether the display was expression homogeneous versus heterogeneous. For this experiment, the program controlling Experiment 4 was changed in only two regards: (a) All 12 conditions that resulted from the orthogonal combination of set size, target face presence, and target face identity, were randomly intermixed within a block of trials; and (b) the smallest set size was two rather than one, because indicating the presence of a different face makes no sense if only one face is presented. The means of the 12 conditions from Experiment 3 and the variation with the new task correlated with $r = .96$, indicating that the task is not of particular importance. The slopes were: ATP = 20 ms; FTP = 42 ms; ATA = 46 ms; FTA = 71 ms; that is, the slopes were somewhat lower but showed the same results pattern as all experiments presented in this article.

Second, it might be objected that the faces were rather small, measuring about 1° of visual angle, while in some of the previous work, larger stimulus sizes have been used. A second control experiment (eight participants) replicated Experiment 3 using faces with diameters twice as large (distances between the stimuli were doubled as well; note, however, that because viewing distance was 120 cm, retinal size was not increased 200% of the original stimuli, but only 150%). The results were very similar to those reported in Experiment 3. The slopes were ATP = 13 ms; FTP = 38 ms; ATA = 35 ms; FTA = 58 ms; that is, the size of the stimuli does not appear to be of particular importance with respect to the overall pattern of results.

EXPERIMENT 5

Although Experiments 2–4 did not render the data pattern of Experiment 1 indicative of a classical search asymmetry, search inequalities were found for all stimulus pairs. Experiment 5 was conducted to test whether these differences are a consequence of the processing of the stimulus as a face. As a means to that end, all stimuli were presented upside down. The logic of inverting the faces relies on the finding that face processing is disturbed when the face is presented upside down (e.g., Thompson, 1980). Thus, this procedure tests the possibility that the configuration of stimulus features (independently of orientation) is sufficient for producing the asymmetry even if face processing is handicapped. As pointed out by Horstmann and Bauland (2006), this logic is not unproblematic, because stimulus inversion may have other consequences than only disturbing face processing (Enns & Rensink, 1990; Kleffner & Ramachandran, 1992; Wolfe, 2001). That is, if the search inequality is eliminated by stimulus inversion, it is unclear whether this was due to the hindering of face processing or, for example, familiarity related factors (cf. Wolfe, 2001). However, if the search inequality is not eliminated, this would indicate that a full processing of the stimulus as a human face is not a necessary condition for the search inequality.

Method

Participants. The participants in this experiment were eight students from Bielefeld University, two men and six women, with a mean age of 24 years ($SD = 3.1$). Five additional participants were tested but not included in the analysis because they exceeded the error criterion (see Experiment 2). Interestingly, the high error rates were not randomly distributed, but occurred exclusively in the difficult search condition when this condition followed the easy condition. Importantly, however, these participants showed exactly the same data pattern as the participants presented here.

Apparatus, stimuli, procedure, and design. These were the same as in Experiment 3 (which was chosen because it revealed the pattern nearest to a search asymmetry), with two exceptions. First, different equipment was used that was, however, comparable to the equipment used before. Second, and most importantly, all stimuli were presented upside down.

Results

Slopes. Figure 6 shows the means for RTs and errors of Experiment 5. The ANOVA of the slopes for RTs (see also Tables 1 and 2) revealed a significant main effect for target presence, indicating shallower slopes for target present than for target absent trials (24 vs. 68 ms/item), and a significant main effect for target identity, indicating that slopes were less steep when the target was an angry face versus a happy face (33 vs. 60 ms/item). A corresponding ANOVA of the slopes for errors also revealed no significant effects.

A search inequality was confirmed, $t(7) = 2.9$, $p < .05$, with angry target faces being detected more efficiently than happy target faces (14 vs. 35 ms/item).

Intercepts. The ANOVA of the intercepts for RTs revealed a significant main effect for target presence, revealing shorter RTs in target present than absent trials (689 vs. 721 ms), but no other effects.

Discussion

Very similar results are obtained with inverted as with upright faces (Experiment 3). Based on the assumption that face inversion hinders face processing, this result suggests that a full processing of the stimulus as a face is not necessary for the effect. Similar correspondences between the search efficiencies for upright and for inverted faces have already been obtained by Öhman et al. (2001) and White (1995).

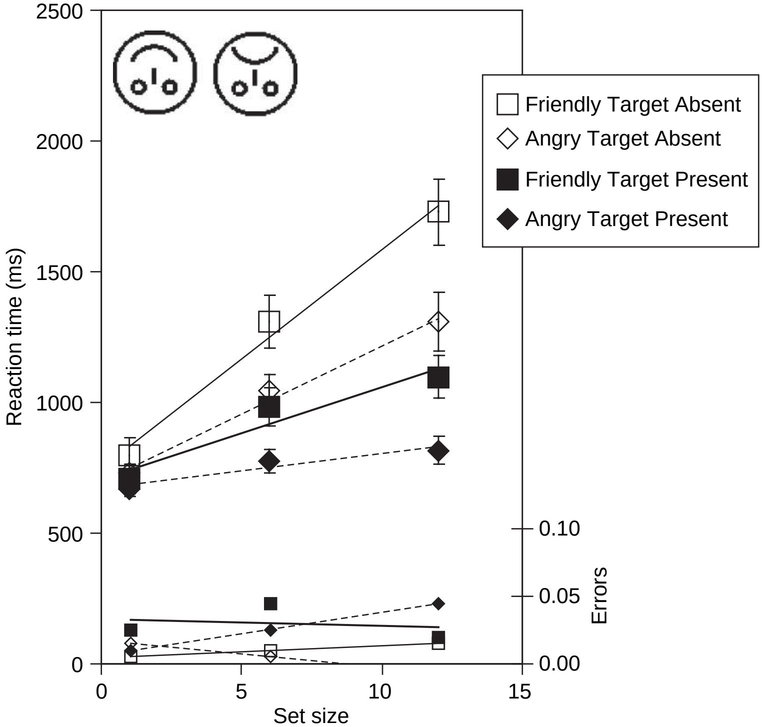

Figure 6. Mean correct RTs and error rates for each of the 12 conditions in Experiment 5. See also Figure 2.

GENERAL DISCUSSION

The starting point of the current investigation was the observation of heterogeneity in the results from previous research using the search asymmetry design with threatening or negative versus friendly or positive facial expressions. It was reasoned that one implication may be that search efficiency varies more within than between the categories of facial threat versus facial friendliness, suggesting stimulus specific, rather than category-based effects. However, an equally plausible cause of the heterogeneity was proposed to result from procedural differences. Thus, the present study tested approximate replicas of previously used stimuli, while holding constant the experimental procedure.

The experiments rendered a number of noteworthy results: (a) Evidence for a preattentive discrimination of threatening or negative faces versus friendly or positive faces was weak at best, replicating most of the previous results. (b) However, a search inequality favouring threatening or negative faces was present in all experiments, though to different degrees. (c) There were considerable differences in the slopes depending on the particular stimulus pair tested. (d) The intercept effect present in some of the previous studies (e.g., Öhman et al., 2001) proved unreliable in the present experiments (Exps. 2 and 4 revealed no intercept effect favouring threatening faces, whereas in Exp. 3, happy faces were responded to faster). (e) The absence of evidence for a preattentive discrimination of facial affect cannot be accounted for by a general insensitivity of the procedure used, because Experiment 1 revealed the expected search asymmetry for a stimulus pair considered a classical example in the visual search literature (cf. Wolfe, 2001); moreover, particulars of the results cannot be attributed to the choice of unusual set sizes or tasks, because the present task had been repeatedly used before in the visual search literature (e.g., Enns & Rensink, 1990; Rauschenberger & Yantis, 2006; Treisman & Souther, 1988). Finally, (f) search efficiency is relatively unaffected by inverting the stimuli, suggesting that dedicated face-processing mechanisms are not too important for the present result.

The slope for the detection of angry faces in happy crowds, averaged over the whole set of experiments, was distinctly larger than 10 ms/stimulus, which is the conventional criterion to conclude that the slope is not zero—in fact, only one slope (12.5 ms/stimulus, Exp. 3) was in the vicinity of "quite efficient search" (Wolfe, 1998). Thus, according to the standards in vision research, there is no convincing evidence for the preattentive discrimination of angry and happy faces.

One might argue that this conclusion amounts to the acceptance of the null hypothesis for attentive processing of facial affect. Note, however, that (a) the failure to find efficient search was repeated, (b) the slopes were in most cases well in the range of nonefficient processing, implying that the failure is not a matter of statistical power, (c) the stimuli were taken from publications that are often cited with reference to a preattentive processing of angry faces, and (d) Experiment 1 clearly demonstrated that the procedure successfully detects efficient search, implying that experimental power too is not an issue. Finally, treating inefficient search as the null hypothesis is somewhat arbitrary and depends on the theoretical stance: If, conversely, preattentive processing is viewed as the null hypothesis, then the null hypothesis is clearly rejected in the present experiments.

Of course, the present results do not literally disprove the existence of a basic dimension of facial threat. In particular, if the difference in facial threat between target and distractors is very small, it is theoretically possible that search is not efficient despite the fact that threat is preattentively available (cf. Treisman & Gormican, 1988). This could be due to two factors: Threat or negative valence is not zero in the distractors, or not sufficiently high in the targets. The first alternative is not quite plausible, because the smiling distractors should be virtually devoid of facial threat. In support of the second alternative it might be pointed out that some of the negative target stimuli might not adequately excite the hypothesized threat-detector. In fact, as all stimuli are schematic it stands to debate whether they capture the relevant characteristics of genuine threatening or friendly faces. However, one result of the present experiments suggests that this is not the main factor: The least efficient search (and the least pronounced search inequality) was obtained with the stimulus pair that is most similar to real faces (i.e., the stimuli from Exp. 2). Moreover, these stimuli were designed to resemble those presented by Öhman et al. (2001), who explicitly assume that their stimuli capture the relevant visual features of threatening faces. Thus, although the present results do not disprove preattentive discrimination of facial threat, they provide a strong argument against it.

The inconclusive evidence for preattentive discrimination of facial affect in the present experiments replicates previous results by Fox et al. (2000), Nothdurft (1993), and Öhman et al. (2001), and is consistent with both attention theories and modern affective neuroscience. In attention research, straightforward examples of basic features (that are available before the deployment of attention and can thus be used to guide attention) are colour, size, orientation, or spatial frequency (cf. Wolfe, 1998; Wolfe & Horowitz, 2004). Spatiovisual attention, in turn, is needed to combine these basic features (e.g., Treisman & Gelade, 1980; Wolfe, 1994) into integrated objects and retrieve their semantic content. It is reasonable to assume that facial expressions of emotion are defined by conjunctions of features because they are rather complex shapes; this suggests that differences in the emotion conveyed by the faces cannot be detected preattentively. Note that stimulus complexity cannot be used to demand a less strict criterion for search efficiency. That is, one can hardly argue that facial expressions are more complex than, for example, circles and lollipops, and that for this reason, different criterions with regard to preattentive processing must apply. Clearly, stimulus complexity is thought to be a cause for inefficient serial search; it would be a weak argument for preattentive processing, if evidence for it is obtained by merely changing the criterion. Note also that there are some examples of a preattentive discrimination of rather complex stimuli, like drawn 3-D cubes lit up from below versus above (Enns & Rensink, 1990; Wolfe, 2001).

In present-day neuroscience theories, LeDoux's theory of dual pathways to the amygdala has attracted much attention in emotion research, and has sometimes been mentioned with respect to the hypothesized threat-advantage for faces (e.g., Mogg & Bradley, 1999; Öhman et al., 2001). Of course, LeDoux's work is relevant on a more general level because it strongly suggests that there can be a rapid, not cortically mediated, detection of threat. However, it does not make specific predictions regarding the visual search task. LeDoux's work was concerned with simple classical conditioning in rats, where the onset or presence of an auditory stimulus was associated with an aversive event (e.g., LeDoux & Armony, 1999; LeDoux, Sakaguchi, Iwata, & Reis, 1986; LeDoux, Sakaguchi, & Reis, 1984). LeDoux and co-workers were able to demonstrate a subcortical, thalamoamygdaloid pathway, which is alone sufficient to promote classical conditioning. Two observations are important. First, this pathway transmits auditory and not visual information, and second, the tasks of detecting a sound versus discriminating faces are separated by several degrees of complexity. Probably, the lateral geniculate nucleus (LGN) in the thalamus, which is the visual analogue to the auditory nucleus implied in the work of LeDoux, is not capable of performing such a complex stimulus analysis: Single-cell recordings from the LGN in the cat reveal that this structure is even incapable of responding to perceptual stimulus differences that clearly support efficient search and perceptual pop-out in psychophysical experiments (e.g., line orientation or blob size; Nothduft, 1990). If the threat advantage in this and previous studies is really emotional in nature, it would most probably be mediated via the corticoamygdaloid pathway.

The search inequality favouring angry target faces was present in all experiments, testifying a phenomenon of considerable robustness. At least two types of explanation can be considered: Perceptual and emotional. A visual perception explanation would regard the effect as a consequence of perceptual differences between the stimuli of a pair. Facial expressions of emotion differ, by necessity, perceptually, consistent with biological theories of signal evolution that predict that evolved signals will be perceptually conspicuous and exaggerated (Dawkins & Krebs, 1978; Fridlund, 1994). On this account, the search inequality is due to perceptual differences between the angry and the happy faces, with the angry faces' features being more conspicuous than those of the happy faces (Horstmann & Bauland, 2006). Note that these might be different for schematic and real faces. With regard to schematic faces, White (1995) has suggested that the smile is harder to see than the frown because it is masked by the face outline. In addition, Horstmann et al. (in press) speculated that schematic angry faces are more difficult to reject as a distractor because they are more complex (see also Rauschenberger & Yantis, 2006, and below). With regard to realistic faces, Horstmann and Bauland (2006) found a pronounced threat advantage in a pair of greyscale images, a threatening and a friendly face, in which differences unrelated to the facial expression were eliminated. Further experiments revealed that the mouth region alone, but not the eyes region, was responsible for the search inequality. Horstmann and Bauland interpreted their results as being in line with a sensory-bias hypothesis that important social signals like facial threat developed in human evolution to exploit extant capabilities of the visual system to the effect of their relative salience and conspicuousness.

Differences in postattentive ("serial") search have also been explained by differences in "the speed at which distractors can be serially checked to determine if they meet the target specification" (Treisman & Souther, 1985, p. 292). In fact, an examination of the target absent slopes reveals a search inequality in these conditions as well. This result indicates that large parts of the search inequality are due to a slower scanning of crowds made up of angry rather than friendly faces.

The speed with which distractors are rejected during serial search depends (inter alias) on the perceptual similarity between the distractors, as well as the dissimilarity between the distractors and the target (Duncan & Humphreys, 1989), on perceptual familiarity (Wolfe, 2001), on perceptual complexity (Rauschenberger & Yantis, 2006), but conceivably also on emotional factors. In serial search, attention is deployed to individual stimuli, resulting in the binding of more elementary features, the establishing of the object representation, and the retrieval of the meaning of the stimulus, which should also concern emotional aspects (Treisman & Gormican, 1988). Possible emotion–attention interactions include difficulties to disengage attention from the angry distractors (Fox et al., 2000; Fox, Russo, & Dutton, 2002; Lipp & Derakshan, 2005), or a constriction of the focus of attention by negative stimuli and a dilation of the focus of attention by positive stimuli (Fenske & Eastwood, 2001; but see Horstmann et al., 2006), all resulting in a more piecemeal processing of angry distractors, while happy distractors are rejected in larger groups. Both types of explanations are consistent with the fact that in target absent slopes, happy crowds (angry target absent conditions) are also scanned faster than angry crowds (happy target absent conditions).

In a recent study, Horstmann et al. (in press) have tested the viability of this postattentive account with schematic faces, consisting of circles as heads, dots as eyes and curved lines as mouths. Positive and negative faces only differed in the orientation of the mouth line, and neutral faces were constructed by superimposing (or merging) the positive and the negative face. Three search conditions revealed the following results: (a) Negative-face targets were found faster in positive-face crowds than vice versa; (b) negative-face and positive-face targets were searched for with equal inefficiency among neutral distractors constructed by superimposing the positive and the negative face; and (c) neutral targets were found faster in positive-face crowds than in negative-face crowds. In sum, the entire pattern of results strongly suggests that the search inequality is due to differing efficient rejection of the distractors, with little or no contribution of the target. Horstmann et al. also discussed problems with regard to neutral distractors. The choice of a neutral distractor is not an easy task—in fact the elegance of the search asymmetry design partly results from the fact that a third "neutral" distractor is not needed. To illustrate, in searching for an O-target versus an F-target among E-distractors, there is probably a search asymmetry favouring the O-target, because the O-target is more dissimilar to the E-distractor than the F-target. In general, the similarity between target and distractors is an important determinant of search efficiency (Duncan & Humphreys, 1989), with search becoming more efficient when the target becomes more dissimilar from the distractors. In visual search experiments with faces, researchers have often used a straight-line mouth in the neutral distractor face. However, although it is quite obvious that this stimulus is affectively neutral, it is less obvious why this stimulus should be regarded as perceptually neutral, too (except in that it is different from both stimuli, of course). In fact, Eastwood et al. (2001), whose target stimuli were very similar to those used by Horstmann et al. (in press), found an advantage for the negative-target face over a positive-target face among straight-line mouth neutral-face distractors. Horstmann et al. argue that their approach of merging the two targets into one neutral distractor is a more comprehensible approach to obtain a neutral target with about equal perceptual similarity with both targets. Either way, the results of Eastwood et al. and Horstmann et al. illustrate that the particular choice of the distractors is crucial and can have considerable effect on the results.

The present experiments revealed large differences in the sizes of the slopes between different stimulus pairs. Because only the specific stimuli differed between the experiments, while the remaining procedural details were constant, this pattern indicates that stimulus factors contribute strongly to search efficiency. This implies that it is not arbitrary what specific facial stimuli are used to test the preattentive threat advantage hypothesis. Previous research has tacitly assumed that most stimulus pairs with a sufficient difference in facial threat (or negative valence) would be equivalent. Of course, given that the preattentive-threat detector hypothesis is correct, this is a reasonable assumption (see introduction); by the same token, the large within-category variation cannot easily be reconciled with this hypothesis.[4]

It can be argued that the research by Lundquist and colleagues (Lundquist, Esteves, & Öhman, 1999, 2004; Öhman et al. 2001) suggests an a priori reason for regarding one face pair as most representative. These authors have argued for the importance of eyebrows in the attribution of

[4] As suggested by one reviewer, a continuous variation of facial threat (e.g., through morphing) in the targets might be helpful. If categorical perception of faces (Calder, Young, Perrett, Etcoff, & Rowland, 1996) affects search efficiency, one would expect a step-function relating the degree of facial threat to search efficiency, but not a linear function.

anger or threat (see also Aronoff, Barclay, & Stevenson, 1988), implying that, when in doubt, the stimuli from Experiment 2 would be preferred. However, Fox et al. (2000) have defended their use of browless faces by proposing that an evolved mechanism for threat detection should be biased towards false alarms (in contrast to misses), and should therefore respond to ambiguous stimuli. Also, in a search experiment with photographic stimuli, Horstmann and Bauland (2006) found that photorealistic brows neither contribute to efficient search, nor to the differences in search efficiency between friendly and angry expressions. In fact, in the present experiments, some of the browless stimuli conform more with the threat advantage hypothesis than the brow-present stimuli, questioning either the threat detector hypothesis or the assumption that eyebrows are essential for the communication of threat.

A comparison with those studies in the literature that used similar stimuli reveals similarities and differences in the results. First, intercept effects (e.g., Öhman et al., 2001) were virtually absent in the present experiments. This is probably due to the fact that the slope of the search function is not constant over the range of set sizes, but is steeper with small set sizes (see Discussion of Exp. 2). Second, White (1995) found virtually flat search slopes, whereas the present experiments found steep search slopes with stimuli intended to be replicas of White's stimuli. A possible explanation is that White's stimuli differed in some respects from the ones presently tested. In all likelihood however, procedural differences contribute to the differences, for example, White used an irregular circular display of 500 ms duration with the task to indicate whether the display was expression homogeneous or heterogeneous. It is difficult to asses the contribution of each of the many differences between the procedures in the production of differences in the effects, but it may well be that the relatively ordered presentation of the faces on an imaginary circle in White's study produced supraelement cues to the presence of the target, which were prevented in the present study by random displacements of the stimuli (cf. Duncan & Humphreys, 1989). A similar account may be given for the difference between present Experiment 4 and the corresponding experiment of Fox et al. (2001).

The evident impact of procedural details on the results patterns indicates possible limitations of the present study: One might ask whether same or different results were obtained with different experimental set-ups, and which design would be considered the most important. The present procedure was chosen because of its similarity to the original experiments on search asymmetries (e.g., Treisman & Souther, 1985). Its features, (a) the use of the three set sizes of 1, 6, and 12 elements, (b) presented in an irregular matrix, (c) with presentation duration until the response was registered, (d) and a constant mapping procedure, that is with a constant target within a given block, have been used in many subsequent studies (e.g., Enns & Rensink, 1990; Rauschenberger & Yantis, 2006; Treisman & Souther, 1988). To elucidate, given that the preattentive threat-advantage hypothesis is true, there were good reasons to expect a classical search asymmetry to show up in the present experiments. However, in the following, I will discuss the strengths and weaknesses of different approaches, and how the particular choices may influence the results.

With regard to the display layout, circular displays reduce the influence of retinal eccentricity, which is valuable, in particular in combination with very short exposure times ($<$ 100 ms) that render eye movements ineffective. The disadvantage is that larger numbers of stimuli require a large circle subtending well in the periphery, such that eye movements would often be obligatory to achieve sufficient acuity for stimulus discrimination. The advantages and disadvantages of matrix displays are complementary. The present study did not restrict presentation duration, consistent with Nothdurft (1990) and Öhman et al. (2001), whereas some of the previous studies did restrict presentation duration (e.g., Fox et al., 2000; White, 1995). Unrestricted viewing is the usual approach when RTs are used as the dependent variable, because the interpretation of RTs presupposes reasonable accurate responses, which is compromised by short presentation durations, in particular with inefficient searches. Consequently, a restriction of viewing duration in RT experiments often pushes parts of the effects into the error proportions. An advantage of restricted presentation durations may be to force participants to use cues to the target that are available for a very efficient search, even if these are rather weak. However, whether the presentation durations of 800 ms and 500 ms used by Fox et al. (2001) and by White (1995), respectively, were sufficiently short to induce such a search strategy, is unknown.

With respect to the task, searching for a prespecified target (e.g., a happy face) in a given block is more frequently used in visual search studies than searching for a discrepant stimulus. One advantage of discrepant-stimulus search is that the observers need not know which target stimulus is used in a given trial. One disadvantage is that the frequent changes between target and distractor (i.e., the inconsistent mapping; Shiffrin & Schneider, 1977) may introduce additional within condition error variance. To my knowledge, systematic differences in evidence for preattentive processing between these two tasks have not been reported; in fact the present control experiment did not find differences.

Stimulus size is also a possible issue: Fox et al. (2000) and Öhman et al. (2001) presented larger stimuli than White (1995), Nothdurft (1993), and the present study. Larger stimuli would excite neurons with larger receptive fields, which are more frequent in the periphery—possibly, the preattentive threat detector is tuned to detect stimuli in the periphery. However, neither Öhman et al. (2001) nor Fox (2000), who used relatively large stimuli, reported search slopes that are reasonably flat to strongly suggest preattentive detection. Also, the present control experiment did also not yield marked differences between small and large stimuli.

To conclude, the present experiments reveal that some of the inconsistencies in the relevant literature disappear when the same experimental paradigm is used. The present experiments with affective faces found rather steep search function for target present trials, not strongly supporting the hypothesis of preattentive discrimination. Another consistent result was the more efficient search with angry than happy faces as targets. The overall pattern of results, however, advises caution with respect to the interpretation that the difference in efficiency (or rather, noneefficiency) is due to the valence of the target: Because happy crowds are scanned through quickly independently of the presence of an angry target, the angry target advantage (or happy target disadvantage) in visual search may possibly be a happy distractor advantage (or angry distractor disadvantage).

How do the present results from the visual search task relate to occasional findings of evidence for preattentive processing from other tasks? For instance, Mogg and Bradley (1999) found faster responses to the position of a dot (left or right) when a masked angry face, but not when a neutral or happy face was flashed on the same rather than on the other side. Or, for another example, Vuilleumier and Schwartz (2001) found reduced extinction in neglect patients for positive and negative schematic faces relative to shapes and neutral schematic faces. These results appear to suggest preattentive processing in some way. The important point is that neither of these reports used standard procedures to test preattentive processing. In contrast, efficient search is (together with effortless texture segregation) the most important criterion for preattentive processing (Wolfe, 1998). Moreover, although the studies mentioned rendered intriguing results that are consistent with the preattentive processing of affect, they are open to other interpretations. For example, Mogg and Bradley's results may be due to perceptual and not to emotional differences between angry and happy faces, and their spatial cueing task may not probe preattentive processing. With the aim of proving preattentive processing with these alternative paradigms, more experimental and theoretical work is probably needed in addition to these results.

In the introduction, I explained that the preattentive threat-detector hypothesis is usually motivated by reference to ecological considerations that the processing of threat has primacy over other forms of information. It is logically possible to falsify the preattentive threat-detector hypothesis without questioning the more general threat-advantage hypothesis. In fact, we have already proposed that social signals should have evolved to exploit the extant capabilities of the visual system so as to ensure high saliency, and that within the system of evolved nonverbal signals, indications of threat may be especially salient (Horstmann & Borgstedt, in press). The present results, revealing a search inequality for threatening faces, may also be viewed in support of a more general threat advantage hypothesis, if one is willing to accept that the schematic faces capture the relevant features of threatening and nonthreatening social signals.

A final remark shall concern a possible misconception. Tentatively assuming that there is no preattentive discrimination of angry and happy faces and that the obtained effects occur only after attention has been directed to the stimuli does by no means imply that the affective appraisal, or threat detection, is done consciously or with intentional effort. Bargh (1989) has reflected extensively on the relation between the concepts of preattentive and attentive processes, conscious and nonconscious processes, and controlled and automatic processes, and his arguments are not repeated here in detail. The central point is that there are no two distinct processing types, one preattentive, unconscious and automatic, and the other post-attentive, conscious, and intentionally controlled. Rather, the attributes may get together in any combination. For example, it may well be that schematic facial stimuli are emotionally appraised nonconsciously and involuntarily via corticoamygdaloid pathways following an attentional processing.

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