Emotion
2008, Vol. 8, No. 2, 151–161

1528-3542/08/$12.00 DOI: 10.1037/1528-3542.8.2.151

Emotional Priming of Pop-Out in Visual Search

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When searching for a discrepant target along a simple dimension such as color or shape, repetition of the target feature substantially speeds search, an effect known as feature priming of pop-out (V. Maljkovic and K. Nakayama, 1994). The authors present the first report of *emotional priming of pop-out*. Participants had to detect the face displaying a discrepant expression of emotion in an array of four face photographs. On each trial, the target when present was either a neutral face among emotional faces (angry in Experiment 1 or happy in Experiment 2), or an emotional face among neutral faces. Target detection was faster when the target displayed the same emotion on successive trials. This effect occurred for angry and for happy faces, not for neutral faces. It was completely abolished when faces were inverted instead of upright, suggesting that emotional categories rather than physical feature properties drive emotional priming of pop-out. The implications of the present findings for theoretical accounts of intertrial priming and for the face-in-the-crowd phenomenon are discussed.

Keywords: facial expressions of emotion, priming of pop-out, repetition priming, visual search

Visual search tasks have been extensively used to investigate what factors determine the allocation of attentional priority (see Müller & Krummenacher, 2006, for a recent review). Visual search models have converged on the notion that search performance results from the interaction of goal-directed (top-down) and stimulus-driven (bottom-up) mechanisms (e.g., Bundesen, 1990; Cave & Wolfe, 1990; Grossberg, Mingolla, & Ross, 1994; Itti & Koch, 2000; Treisman & Sato, 1990; Wolfe, 1994). Goal-directed factors refer to the observer's intentions during search, and include the defining characteristics of the target, such as its known color or shape (e.g., Duncan & Humphreys, 1989), and the location at which it is expected to appear (e.g., Shaw & Shaw, 1977). Stimulus-driven aspects of a visual scene that were found to attract attention include physically salient objects (e.g., large or bright objects, Yantis & Egeth, 1999), objects that possess a unique property (e.g., the only red object among green ones, Egeth, Jonides, & Wall, 1972; Theeuwes, 1992), and abrupt onsets (e.g., Jonides & Yantis, 1988).

Complex visual stimuli that are not physically salient but are of particular biological significance for the organism were also found to draw attention. For instance, facial expressions of emotion provide powerful signals for rapid nonverbal communication and are thus particularly important for guiding social and motivational activities (Darwin, 1904; Öhman, 1993). Accordingly, various behavioral studies have shown that certain emotional expressions have a special status in attention. In visual search for a unique target among distractors, detection times were found to be faster and search more efficient when the target was an angry face among neutral faces, than when it was a neutral face among angry faces (e.g., Fox et al., 2000; Schubo, Gendolla, Meinecke, & Abele, 2006), an effect that has been labeled "the face-in-the-crowd" effect. Converging evidence supporting the notion of stimulus-driven guidance of attention by certain facial expressions of emotion has come from a variety of other paradigms (e.g., dot-probe task, Mogg & Bradley, 1999; attentional blink, Ogawa & Suzuki, 2004; and spatial cueing task, Fox, Russo, Bowles, & Dutton, 2001; Stormark, Nordby, & Hugdahl, 1995).

Recent research has demonstrated a striking role for yet a third class of factors affecting visual search performance that cannot readily be assimilated to either stimulus-driven or goal-directed factors and are grouped under the name of "implicit visual memory" factors (e.g., Chun & Nakayama, 2000; Wolfe, Butcher, Lee, & Hyle, 2003). Several mechanisms were found by which attention-related intertrial memory traces speed search performance (e.g., Lamy, Bar-Anan, & Egeth, in press; Maljkovic & Nakayama, 1994, 1996; Müller, Heller & Ziegler, 1995). For instance, Maljkovic and Nakayama (1994) discovered that in search for a color singleton target, when target and nontarget colors are switched unpredictably from trial to trial, response to the target is faster when the target color is the same as in a preceding trial than when it is different, a phenomenon that they called *priming of pop-out* (PoP, see also, Goolsby & Suzuki, 2001; Huang, Holcombe, & Pashler, 2004; Lamy, Carmel, Egeth, & Leber, 2006; Wolfe et al., 2003). Performance was also enhanced when the target occupied the same spatial position on consecutive trials (Maljkovic & Nakayama, 1996). Such effects of previous *attentional allocation* during visual search should be distinguished from the effects of simple previous exposure on visual processing, which have long been documented in priming studies (e.g., Musen & Treisman, 1990).

The role of such intertrial effects has typically been neglected in current theorizing about visual search mechanisms. Yet, this role appears to be crucial, in light of recent evidence suggesting that we

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Support was provided by the Israel Science Foundation (ISF) Grant no. 1382-04 to D.L.

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have very poor memory of the details of scenes we have just been exposed to (e.g., Grimes, 1996; Ballard, Hayhoe, & Pelz, 1995). Within this context, Maljkovic and Nakayama (2000) suggested that implicit visual memory processes "...could bias attentional shifts and eye movements without need for a supervisory control, and would ensure that objects of recent interest would be repeatedly sampled. Furthermore, the short-term nature of the memory would make sure that the appropriate biasing would be up-to-date, tuned to the current objects of interest" (p.593).

The effects of intertrial priming mechanisms on visual search performance have been demonstrated for simple object properties such as color (e.g., Maljkovic & Nakayama, 1994), orientation (e.g., Hillstrom, 2000), and shape (e.g., Lamy et al., 2006), as well as location (Maljkovic & Nakayama, 1996). Findings suggesting that PoP occurs for conjunction of features[1] have also been reported, but are less compelling, as repetition of feature conjunctions was confounded either with switching between attentional sets (Hillstrom, 2000) or with top-down expectations for a particular conjunction of features (Kristjansson, Wang, & Nakayama, 2002). Yet, it is important to determine whether intertrial priming mechanisms facilitate search in natural environments, namely, whether they also operate for more complex stimuli that are crucial for effective adjustment in real-life situations, such as facial expressions of emotion. That is, if at a given moment in time an observer attends to a face displaying a particular emotion, say, anger, will this observer be faster to respond to an angry face that he or she encounters shortly afterward?

The objective of the present study was to investigate whether implicit visual memory for recently attended features affects search performance when the target and distractors are distinguished by their emotional category, namely, by the facial expression of emotion they display. To this end, we used a variant of Maljkovic and Nakayama's (1994) PoP paradigm. On each trial, four face pictures displaying the same individual were presented. On target-absent trials, all the faces in the display were identical. On target-present trials, the target was either an emotional face among neutral faces or a neutral face among emotional faces. That is, the target and nontarget features switched unpredictably from trial to trial. Participants had to detect the presence of a face displaying a discrepant emotional expression. If implicit memory for a recently attended facial expression of emotion speeds the search for a target displaying the same facial emotion, then we should expect "emotional PoP" to occur. For instance, if the target on the current trial is an angry face among neutral faces, we should expect reaction times to be faster if the previous target had also been an angry face among neutral faces than if it had been a neutral face among angry faces.

A distinctive feature of emotional stimuli is that, unlike basic features such as orientation or shape, they are valenced, that is, they are typically perceived as positive, negative, or neutral. The results from previous visual search studies show that faces displaying valenced emotional expressions (e.g., angry or happy faces) are more potent in drawing attention than neutral faces (e.g., Eastwood, Smilek, & Merikle, 2001; Fox et al., 2000). Some reports also suggest that negatively valenced facial expressions, specifically, faces displaying threat-related emotions such as anger or fear, guide attention more efficiently than positive facial expressions (e.g., Hansen & Hansen, 1988). Thus, the question arises whether the strength of the memory traces laid down by a recently attended emotional expression might be related to the efficiency of this emotional expression in guiding attention. In other words, do facial expressions that guide attention more efficiently also produce stronger PoP effects? To address this question, we examined whether emotional PoP is modulated by stimulus valence. Search displays contained either neutral and angry faces (Experiment 1A) or happy and neutral faces (Experiment 2A). In each experiment, we compared emotional PoP for emotional (angry or happy) targets relative to neutral targets. In addition, we compared the magnitude of emotional PoP for negative (angry) targets relative to positive (happy) targets.

It is noteworthy that with the present setup, emotional PoP effects are likely to reflect memory traces of emotional categories rather than of physical stimulus properties because the faces presented on two successive trials typically displayed different individuals. For instance, on repeated target-emotion trials, a target representing an angry male could follow a target representing an angry female.[1] Thus, by contrast with "same-feature" consecutive targets which were physically identical in previous PoP studies (e.g., Maljkovic & Nakayama, 1994), same-emotion consecutive targets in the present study largely differed in their constituent features.

One might still argue that the physical features common to different faces displaying the same emotion (e.g., orientation of the dark lines representing the eyebrows) rather than the emotional category per se might account for the repetition effects. To control for this possibility, two additional experiments were conducted, in which the displays included inverted faces (Experiments 1B and 2B) instead of upright faces (Experiments 1A and 2A). Numerous studies have shown that configural information is critical in face processing but is difficult to encode when a face is inverted (e.g., Rhodes, Brake, & Atkinson, 1993; Tanaka & Farah, 1993; Valentine, 1988). Based on these findings, the face inversion manipulation is often used to distinguish between effects of emotional category and stimulus physical properties (e.g., Eastwood et al., 2001; Williams, Moss, Bradshaw, & Mattingley, 2005; Fox & Damjanovic, 2006).

Finally, although not a central objective of the present study, the procedure we used also allowed us to examine the face-in-the-crowd effect, that is, to measure target detection performance as a function of target/distractors emotional expressions, with veridical faces. In order to control for the physical differences between different facial expressions of emotion, most studies of the face-in-the-crowd effect have used schematic faces (e.g., Eastwood et al., 2001; Fox et al., 2000; Öhman, Lundqvist, & Esteves, 2001). Yet, although schematic faces are known to reliably convey emotional expressions, they are indisputably ecologically impoverished (see Horstmann & Bauland, 2006 for a detailed argumentation). Juth, Lundqvist, Karlsson, and Öhman (2005) even reported contradictory findings using veridical versus schematic faces within the same study. Only five previous studies known to us have used veridical faces in visual search tasks, but they have yielded inconclusive evidence. Some of them lacked adequate

[1]The term "Priming of pop-out" was initially created to refer to repetition of the feature of a pop-out target, that is, in the context of efficient search. However, in later studies that investigated the effects of feature repetition for targets that do not pop out, the term "Priming of pop-out" remained. To conform to this convention and facilitate reference to the relevant literature background, we also use this term here, although search for a face displaying a discrepant emotion is typically not efficient.

control for differences in physical salience between the compared emotional faces (Hansen & Hansen, 1988 - see Purcell, Stewart, & Skov, 1996; Gilboa-Schechtmann, Foa, & Amir, 1999; Juth et al., 2005). Others used a blocked design (Williams et al., 2005; Horstmann & Bauland, 2006). That is, for instance, subjects might search for an angry target among happy distractors in a given block of trials and for a happy target among angry distractors in another block of trials. However, a blocked design may not be appropriate to determine whether a certain stimulus property is able to draw attention and may instead reveal the extent to which a template for this stimulus property is able to guide search. The one study that used veridical faces in a mixed design and controlled for physical stimulus differences by running an inverted-faces condition was reported by Fox and Damjanovic (2006). This study was especially designed to test the claim that angry faces are more readily detected than neutral or happy faces and therefore did not address the status of happy faces relative to neutral ones. In the present experiment, we used veridical faces and examined whether an emotional face (either an angry face – Experiment 1A, or a happy face – Experiment 2A) among neutral faces is detected faster than a neutral face among emotional faces, with randomly mixed emotional- and neutral-target trials. Thus, the status of both angry and happy faces could be evaluated relative to neutral faces. We controlled for physical feature differences by testing both upright and inverted faces. It should be noted that because the main focus of the present study was on emotional PoP, we did not manipulate the number of distractors present in the search arrays. Thus, we could not investigate search efficiency (measured by search slope, that is, as the extra search time required by each added distractor) but only overall detection times (see also Fox et al., 2000, Exps 1-4; Juth et al., 2005; Fox & Damjanovic, 2006; Gilboa-Schechtmann et al., 1999; Karparova, Kersting, & Suslow, 2005; Lundqvist & Öhman, 2005).

To summarize, the main objective of the present study was to determine whether PoP occurs with emotional facial expressions and the extent to which it is modulated by emotional valence. A corollary objective was to further investigate the face-in-the crowd phenomenon with veridical faces.

Method

The present study consisted of four experiments run on different participants. The four experiments (1A, 1B, 2A, and 2B) were similar except for the stimuli used, as detailed below.

Participants

Participants were 66 Tel-Aviv University undergraduate students who participated in the experiments for course credit. All reported having corrected-to-normal visual acuity. All experiments included an equal number of male and female participants.

Apparatus

Displays were generated by an Intel Pentium 4 computer attached to a 17" CRT monitor, using 640 × 480 resolution graphics mode. Responses were collected via the computer keyboard. A chin-rest was used to set viewing distance at 50 cm from the monitor.

Stimuli

The fixation display was a gray plus sign (1.14 × 1.14 degree of visual angle) in the center of a black background. The face stimuli were photographs of 16 different Caucasian individuals (eight men and eight women) selected from the MacArthur battery of facial expressions stimuli (NimStim stimulus set: http://www.macbrain.org/faces/index.htm), with open-mouth stimuli. The stimuli consisted of upright faces displaying either a neutral or an angry expression in Experiment 1A, and either a neutral or a happy expression in Experiment 2A. In Experiments 1B and 2B, the stimuli were the same as in Experiments 1A and 1B, respectively, but were presented in inverted rather than in upright orientation.

All pictures were gray-scaled (8 bits) and inserted behind a black overlay with a rounded central aperture subtending about 3.6° horizontally and 4.2° vertically. Mean luminance and contrast were matched between the pictures of the three different emotions of each individual.

Examples of the stimulus displays are presented in Figure 1. Each stimulus display consisted of the fixation display with four photographs of the same individual at the corners of an imaginary rectangle subtending 10.97° in height and 8.84° in width, and centered at fixation. The center of each face photograph was distant from the center of the screen by 3.93°. In the target-absent condition, all four faces displayed the same emotional expression, either valenced (Angry-crowd target-absent condition in Experiments 1A and 1B and Happy-crowd target-absent condition in Experiments 2A and 2B) or neutral (Neutral-crowd target-absent condition in all experiments). In the target-present condition, one of the four faces displayed a different emotion, that is, there was either a valenced face among neutral faces (Angry target-present condition in Experiments 1A and 1B, and Happy target-present condition in Experiments 2A and 2B), or a neutral face among valenced faces (Neutral target-present condition in all experiments).

Procedure

Each trial began with the presentation of the fixation display for 500 ms. It was followed by the stimulus display that remained visible until response or for 2,000 ms. The next trial began after 500 ms. Half of the participants were instructed to detect the presence of a target by pressing "3" with their right index finger if one face was different from the others (target-present response) and "z" with their left index finger if all faces were identical (target-absent response). The remaining participants were assigned the opposite key-to-response mapping for counterbalancing purposes. The experimenter did not refer to the fact that the target differed from nontargets by its emotional expression. Participants were instructed to respond as quickly as possible, while maintaining high accuracy. Error trials were followed by a 500-ms feedback beep. Eye movements were not monitored, but participants were explicitly requested to maintain fixation throughout each trial.

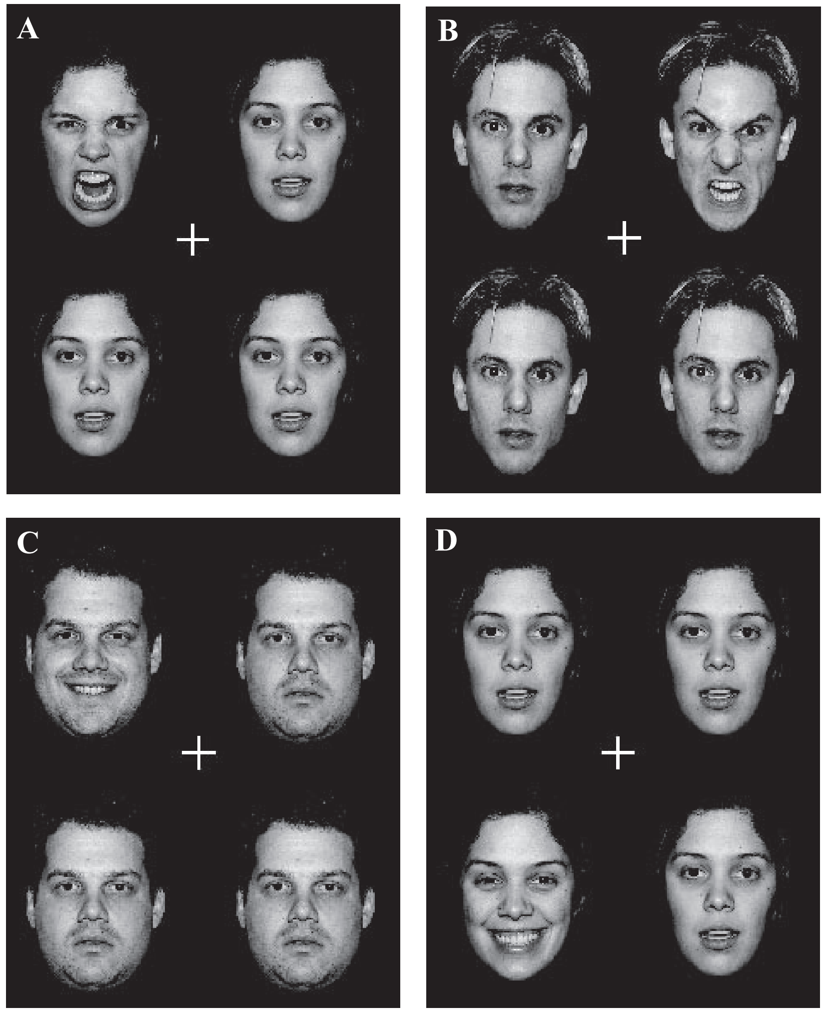

Figure 1. Examples of the visual search arrays. Panels A and B are examples of Angry target-present trials (Experiment 1A). Panels C and D are examples of Happy target-present trials (Experiment 2A). Exactly the same arrays were presented but rotated by 180° in Experiments 1B and 2B (inverted faces).

Design

On each trial, each face identity was equally likely to appear. On target-present-trials, all target positions (upper left, upper right, lower left, and lower right) were equiprobable. Target presence (target-present vs. target-absent) and emotion (Angry vs. Neutral in Experiments 1A and 1B and Happy vs. Neutral in Experiments 2A and 2B) were randomly mixed within-subject variables. Each experiment began with one block of 50 practice trials, followed by 720 trials divided into 9 blocks of 80 trials each.

Results and Discussion

Across all experiments, the data from eight participants were excluded from the analyses because they made more than 25% of errors ($n = 3$) or had mean reaction times (RTs) that deviated from the mean RT of their experiment by more than 3 *SD* ($n = 5$). Thus, the data from 58 participants were analyzed (16 in Experiment 1A, 14 in Experiment 1B, 14 in Experiment 2A, and 14 in Experiment 2B). In all RT analyses, error trials (6.0%, 6.4%, 6.1%, and 4.6% in Experiments 1A, 1B, 2A, and 2B, respectively) were excluded. On correct trials RTs were sorted by conditions of target presence and emotion. Outlier trials within each of the resulting condition cells were excluded from analysis (less than 1% of all trials).

Emotional Priming of Pop-Out

Because we were primarily interested in target detection and how it is affected by intertrial repetition of target attributes, target-absent trials, as well as target-present trials that were preceded by a target-absent trial were not included in the analysis of the emotional PoP effect. Trial sequences that involved the same face identity on successive trials were excluded from analysis in order to avoid contamination of the effect of emotion repetition by the effect of physical features repetition.

Mean RTs and accuracy scores are depicted in Figure 2. For each experiment, a separate Analysis of Variance (ANOVA) was

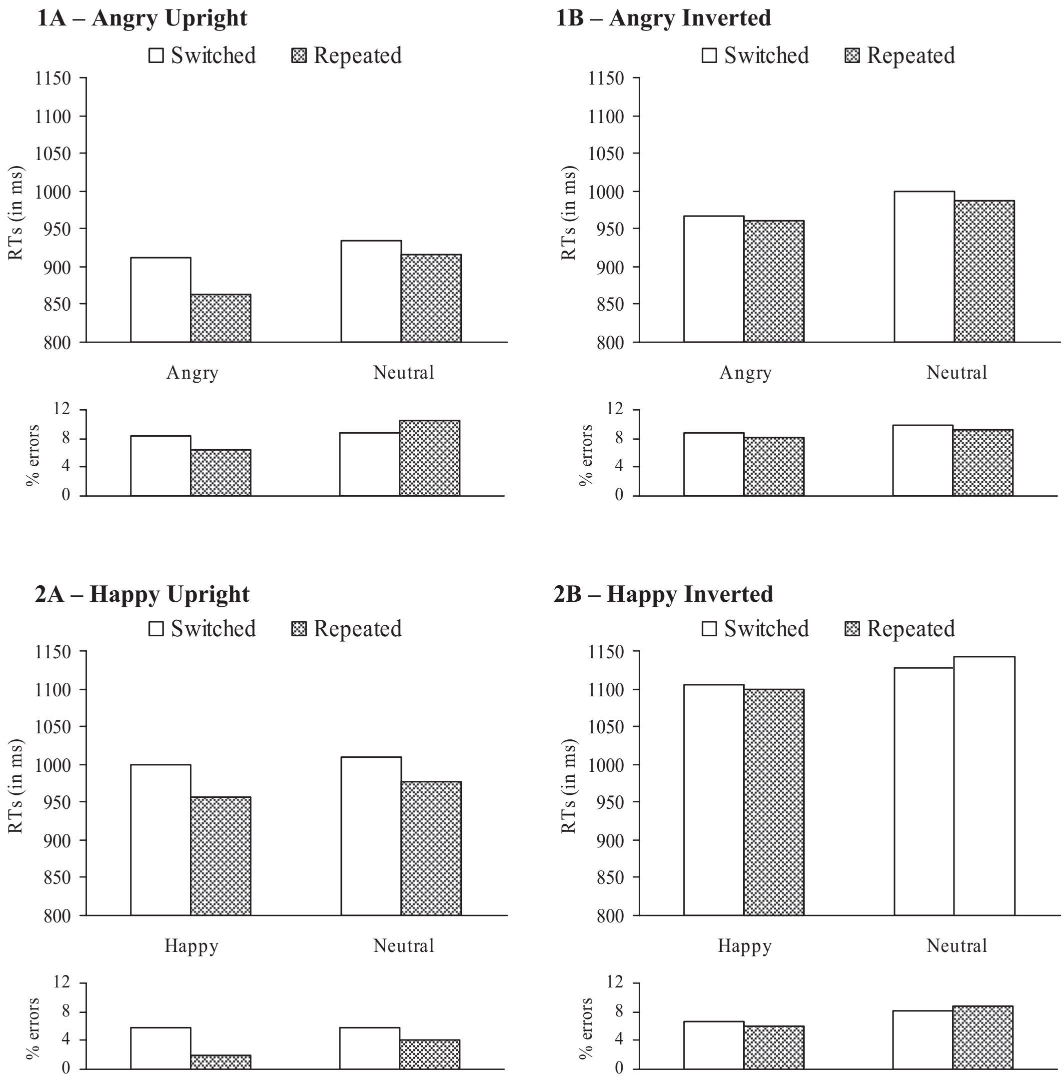

Figure 2. Mean reaction times in milliseconds (upper graphs in all four panels) and mean error rates in percentage (lower graphs) for target-present trials preceded by a target-present trial. Panels 1A and 2A are for upright faces and Panels 1B and 2B are for inverted faces. Panels 1A and 1B correspond to Angry-Angry versus Neutral-Angry sequences and to Neutral-Neutral versus Angry-Neutral sequences (Angry- and Neutral-target conditions, repeated vs. switched, respectively). Panels 2A and 2B correspond to Happy- Happy versus Neutral-Happy sequences and for Neutral-Neutral versus Happy-Neutral sequences (Happy- and Neutral-target conditions, repeated vs. switched, respectively).

conducted on target-present trials preceded by a target-present trial, with Emotion (Angry vs. Neutral in Experiments 1A and 1B and Happy vs. Neutral in Experiments 2A and 2B) and repetition of emotion (no repetition vs. repetition[2]) as factors. Planned comparisons showed that repetition of emotion speeded performance when the target displayed an emotional expression. For Angry-target trials, Angry-Angry target sequences (M = 864 ms) were faster than Neutral-Angry target sequences (M = 911 ms), $F(1, 15) = 6.94$, $p < .02$. For Happy-target trials, Happy-Happy target sequences (M = 956 ms) were faster than Neutral-Happy target sequences (M = 1,000 ms), $F(1, 13) = 10.07$, $p < .008$. A between-experiment analysis showed that the interaction between Experiment (Angry vs. Happy, Experiment 1A vs. 2A, respectively) and repetition of emotion for emotional targets (i.e., excluding Neutral-target trials) was nonsignificant, $F < 1$. That is, the emotional PoP effect did not differ whether the target displayed an Angry emotion (M = 47 ms, Experiment 1A) or a Happy emotion (M = 44 ms, Experiment 2A).

Planned comparisons showed that repetition of emotion when the target displayed a neutral expression did not significantly affect performance. The RTs did not differ for Neutral-Neutral (M = 917 ms) relative to Angry-Neutral (M = 935 ms) target sequences, $F(1, 15) = 1.64$, $p > .2$ (Experiment 1A), and for Neutral-Neutral (M = 977 ms) relative to Happy-Neutral (M = 1,010 ms) target sequences, $F(1, 13) = 2.57$, $p > .1$ (Experiment 2A). A between-experiment analysis showed no difference in the magnitude of the emotion-repetition effect for Neutral targets in an Angry crowd ($M = 18$ ms, Experiment 1A) versus a Happy crowd, ($M = 33$ ms, Experiment 2A), $F < 1$.

Analyses of accuracy data revealed no significant results, all *Fs* <1, except for a trend towards higher accuracy on Happy–Happy ($M = 98.1\%$) relative to Neutral-Happy ($M = 94.2\%$) target sequences, $F(1, 13) = 4.21$, $p < .07$.

To explore whether the emotional PoP effects observed in Experiments 1A and 2A truly reflected the effects of emotion processing rather than physical similarities between faces displaying the same emotion, the same analyses were conducted with inverted faces (Experiments 1B and 2B). These revealed no effect of emotion repetition with inverted faces. There was no effect for emotional targets, that is, no difference either between Angry-Angry ($M = 960$ ms) and Neutral-Angry ($M = 966$ ms) target sequences, $F(1, 13) = 1.21$, $p >$ .2, or between Happy-Happy ($M = 1{,}100$ ms) and Neutral-Happy ($M = 1{,}106$ ms) target sequences, $F < 1$. Likewise, there was no effect for neutral targets, that is, no difference either between Neutral-Neutral ($M = 988$ ms) and Angry-Neutral ($M = 1{,}000$ ms) target sequences, $F(1, 13) = 1.15$, $p > .3$, or between Neutral-Neutral ($M =$ 1,141 ms) and Happy-Neutral ($M = 1{,}127$ ms) target sequences, $F <$ 1. Analyses of accuracy data revealed no significant results, all *p*s > 0.1.

There was a numerical trend toward faster RTs in experiments that involved upright faces relative to experiments that involved inverted faces, on the trials relevant to the assessment of repetition effects (i.e., target-present trials preceded by target-present trials). This effect did not reach significance when the target face expression was angry, ($M = 887$ ms vs. $M = 960$ ms for upright vs. inverted faces, Experiment 1A vs. 1B, respectively), $t(28) = 1.30$, $p > .2$ and approached significance when the target expression was happy ($M = 990$ ms vs. $M = 1{,}117$ ms for upright vs. inverted faces, Experiment 2A vs. 2B, respectively), $t(26) = 1.83$, $p < .08$. This difference raises the possibility that experiments involving inverted faces may have been less sensitive to intertrial effects, because as consecutive trials were more distant from each other in time, such intertrial effects had more time to dissipate. If this was the case, then emotional PoP effects may have occurred for both upright and inverted faces but could be measured only for upright faces. This alternative account would imply that the emotional PoP effect we observed with upright faces may have resulted from repetition of physical features that are common to upright and inverted faces rather than from repetition of emotional category that is unique to upright faces.

In order to test this issue, another type of intertrial repetition effect was examined, namely, location PoP. This effect, which shows that subjects are faster when the target appears at the same location rather than at different locations on successive trials, is typically of the same magnitude or smaller than feature PoP (e.g., Maljkovic & Nakayama, 1996).[2] Thus, it is reasonable to suggest that if the longer RTs observed with inverted faces made it more difficult to measure the effect of emotion repetition, then the same should happen with the effect of location repetition. Our results did not support this prediction. Indeed, planned comparisons showed that subjects were significantly faster when the target occupied the same spatial location on successive trials than when it occupied different locations. This was true whether the displays involved inverted Angry and Neutral faces, ($M = 958$ ms for same target-location trials vs. $M = 977$ ms for different target-location trials), $t(13) = 2.19$, $p < .05$, or inverted Happy and Neutral faces ($M = 1{,}098$ ms for target-location trials vs. $M = 1{,}146$ ms for different target-location trials), $t(13) = 3.46$, $p < .005$. Most relevant to the issue at hand, location PoP was equally strong whether the faces appeared in upright or in inverted orientation (37 ms vs. 21 ms in Experiment 1A vs. 1B, and $M = 39$ ms vs. $M = 48$ ms in Experiment 2A vs. 2B). Indeed, the interaction between orientation (upright vs. inverted) and location priming (same vs. different target location) was non significant both when the displays included Angry and Neutral faces, and when they included Happy and Neutral faces, *Fs* <1. Analyses of accuracy data indicated that there were no significant speed–accuracy trade-offs. It is therefore unlikely that the absence of emotional PoP for inverted faces resulted from the fading of memory traces due to longer RTs in Experiments 1B and 2B relative to Experiments 1A and 2A.

Visual Search for Emotional Faces

Mean RTs and accuracy scores are presented in Figure 3. Separate ANOVAs for each experiment were conducted with Emotion (Angry vs. Neutral, Experiments 1A and 1B, and Happy vs. Neutral, Experiments 2A and 2B) and target presence (present vs. absent) as within-subject factors. The interaction between the two factors was significant in all four experiments, $F(1, 15) =$ 14.97, $p < .002$ in Experiment 1A, $F(1, 13) = 10.86$, $p < .006$ in Experiment 1B, $F(1, 13) = 5.70$, $p < .04$ in Experiment 2A, and $F(1, 13) = 15.65$, $p < .002$ in Experiment 2B. Follow-up comparisons were thus conducted separately for target-present and target-absent trials.

Upright faces. On target-present trials, paired comparisons showed that an emotional target among neutral distractors was detected faster than a neutral target among emotional distractors. This effect was significant when the target displayed an angry expression ($M = 844$ ms) relative to a neutral expression ($M =$ 890 ms), $F(1, 15) = 24.58$, $p < .0002$ (Experiment 1A), and only approached significance when it displayed a happy expression ($M = 964$ ms) relative to a neutral expression ($M = 973$ ms), $F(1, 13) = 3.49$, $p < .09$ (Experiment 2A). A between-experiments analysis showed that the interaction between Emotion (Valenced vs. Neutral target) and Experiment (Angry vs. Happy, Experiment 1A vs. 2A, respectively) was significant, $F(1, 28) = 8.31$, $p <$ .008, thus confirming that the RT advantage in detecting an emotional face relative to a neutral face was significantly larger for Angry faces ($M = 46$ ms) than for Happy faces ($M = 9$ ms).

In addition, paired comparisons showed that target-absent responses were slower for displays containing only emotional faces than for displays containing only neutral faces. Again, this effect was significant for Angry-crowd trials ($M = 873$ ms) relative to Neutral-crowd trials ($M = 831$ ms), $F(1, 15) = 5.83$, $p < .03$, and only approached significance for Happy-crowd trials ($M = 986$ ms) relative to Neutral-crowd trials ($M = 945$ ms), $F(1, 13) = 4.54$, $p < .06$.

[2]Because there were not enough trials to investigate the effects of more than one repetition separately, repetition trials were trials in which the target displayed the same emotion on *at least* two consecutive target-present trials.

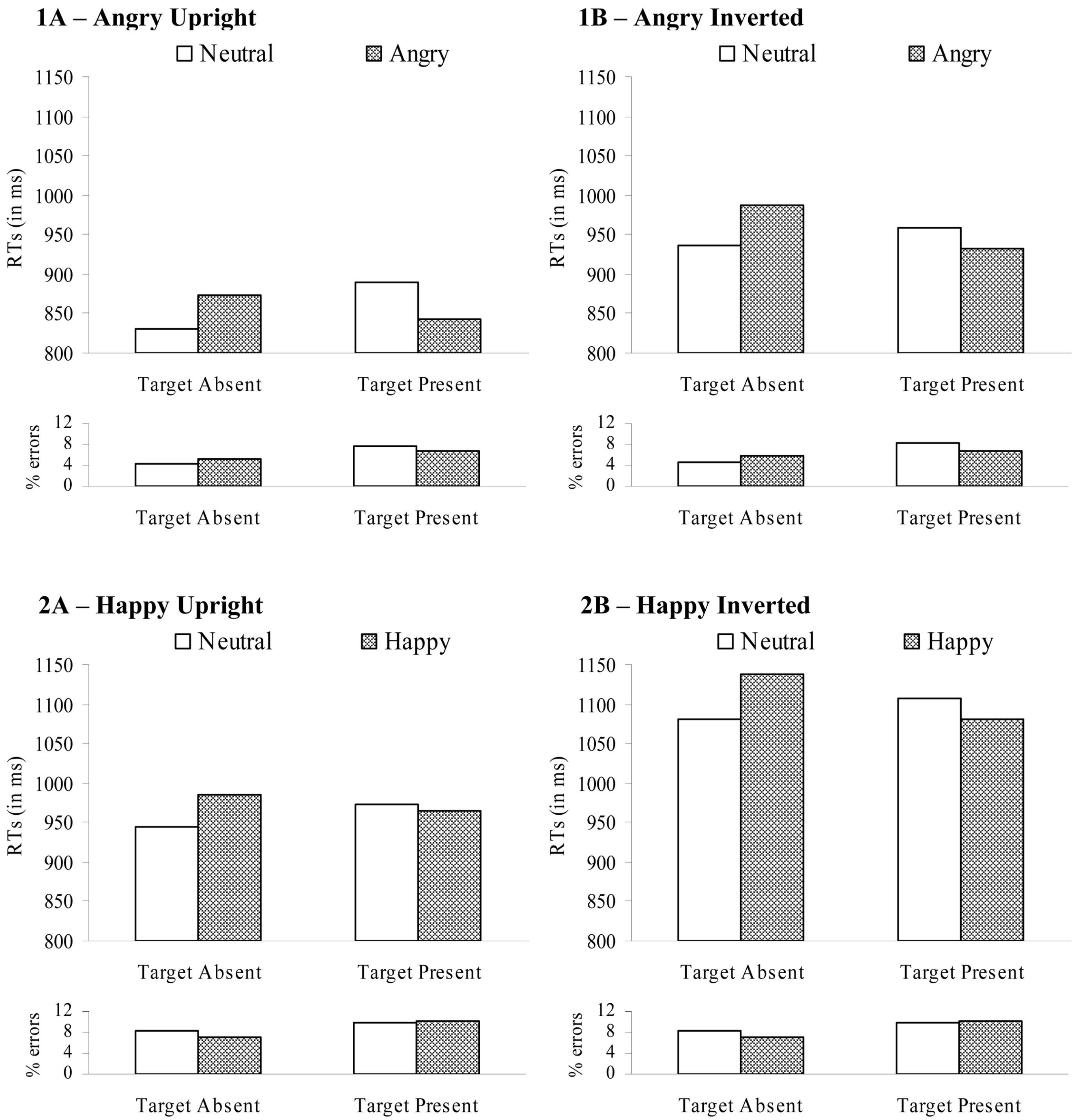

Figure 3. Mean reaction times in milliseconds (upper graphs in all four panels) and mean error rates in percentage (lower graphs). Panels 1A and 2A are for upright faces and Panels 1B and 2B are for inverted faces. Panels 1A and 1B correspond to Angry versus Neutral trials for the target-present and target-absent conditions. Panels 2A and 2B correspond to Happy versus Neutral trials for the target-present and target-absent conditions.

A between-experiments analysis showed that the interaction between Emotion (Valenced vs. Neutral crowd) and Experiment (Angry vs. Happy, Experiment 1A vs. 2A, respectively) was nonsignificant, $F < 1$. That is, slowing on Valenced- relative to Neutral-crowd trials did not differ significantly between Angry-crowd trials ($M = 42$ ms) and Happy-crowd trials ($M = 41$ ms).

Inverted faces. The same analyses were conducted with inverted faces. An emotional target among neutral distractors was again detected faster than a neutral target among emotional distractors. This effect was significant both when the target was an Angry face ($M = 933$ ms) relative to a Neutral face ($M = 958$ ms), $F(1, 13) = 6.60$, $p < .03$, and when the target was a Happy face

(M = 1,080 ms) relative to a Neutral face (M = 1,108 ms), $F(1, 13) = 9.06$, $p < .01$. However, unlike what was found with upright faces, the effect was similar for the two emotions, (M = 25 ms for Angry targets vs. M = 28 ms for Happy targets), $F < 1$. Likewise, target-absent responses were slower for displays containing only emotional inverted faces than for displays containing only neutral inverted faces, both for Angry-crowd trials (M = 986 ms) relative to Neutral-crowd trials (M = 937 ms), $F(1, 15) = 5.83$, $p < .03$, and for Happy-crowd trials (M = 1,139 ms) relative to Neutral-crowd trials (M = 1,081 ms), $F(1, 13) = 10.39$, $p < .007$, with no difference between the two effects (M = 50 ms vs. M = 58 ms, respectively), $F < 1$.

On the one hand, these findings suggest that salience of the stimuli physical properties played an important role in driving the advantage of searching for an emotional face among neutral faces relative to searching for a neutral face among emotional faces, as this advantage was highly significant for both upright and inverted faces. On the other hand, the finding that this advantage was significantly larger for Angry faces than for Happy faces, only with upright faces but not with inverted faces, suggests that emotional category also contributes to drawing attention to Angry faces, but not to Happy faces. This conclusion was also supported when examining the interaction between Emotion (emotional vs. neutral) and Orientation (upright vs. inverted) for target-present trials. This interaction approached significance for angry facial expressions, indicating that the RT advantage for Angry targets relative to Neutral ones tended to be larger for upright faces (M = 53 ms, Experiment 1A) than for inverted faces (M = 24 ms, Experiment 1B), $F(1, 28) = 3.38$, $p < .08$. This interaction was not significant for happy facial expressions: in fact, the RT advantage for Happy targets relative to Neutral ones tended to be smaller with upright faces (M = 9 ms, Experiment 1A) than with inverted faces (M = 28 ms, Experiment 1B), $F(1, 28) = 1.23$, $p > .2$.

Accuracy data showed numerical trends in the same direction, thus removing any concern of speed–accuracy trade-offs. None of these trends approached significance, $Fs < 1$, except for higher accuracy for inverted Angry targets (M = 93.2%) versus inverted Neutral targets (M = 91.6%) on target-present trials, $F(1, 13) = 3.66$, $p < .08$ and lower accuracy for inverted Angry crowds (M = 94.2%) versus inverted Neutral crowds (M = 95.5%) on target-absent trials, $F(1, 13) = 5.85$, $p < .04$.

General Discussion

Emotional PoP

Recent research shows that attentional selection of relevant information is greatly influenced by the stimuli that have been attended in the immediate past, as reflected by powerful intertrial effects in visual search tasks (see Kristjansson, 2006; Chun & Nakayama, 2000 for reviews). Our objective in the present study was to investigate whether such intertrial priming effects, which have so far been demonstrated only with simple features, also occur with facial expressions of emotion, that is, with more complex stimuli of high ecological and interpersonal value. Using a variant of Maljkovic and Nakayama's (1994) PoP task, we showed that in search for the face displaying a discrepant emotional expression, detection performance was better when the emotional expression of the current target was the same as that of the preceding target than when it was different. Thus, the present study is the first report of an *emotional PoP* effect. It is also the first report of a PoP effect with complex stimuli, that was not confounded with either top-down expectancies (as the target and distractor emotions switched randomly from trial to trial) or task switching costs (as the task set—searching for the discrepant emotion—was constant throughout each experiment).

Two arguments favor the interpretation of this emotional PoP effect as resulting from repetition of emotional category rather than of physical stimulus properties. First, the faces presented on two successive trials displayed different individuals and were therefore physically different, such that the small potential physical feature overlap between successive same-emotion targets is unlikely to have produced the emotional PoP effects. Second, face inversion is known to impair perception of emotional expressions (e.g., Calder, Young, Keane, & Dean, 2000) and we found emotional PoP effects to occur with upright faces but not with inverted faces.

The emotional PoP effects reported here were equally large when the target face displayed an angry expression or a happy expression, but showed only nonsignificant trends when the target face displayed a neutral expression. These findings suggest that the magnitude of emotional PoP is modulated by emotional arousal rather than by emotional valence. In addition, it should be noted that the degree of specificity of the memory traces that drove the emotional PoP reported here remains to be determined. Indeed, the comparison from which the emotional PoP effect resulted always involved a sequence of two targets displaying the same emotional expression versus a sequence of a target displaying that emotional expression preceded by a target displaying a neutral expression (e.g., an Angry-Angry sequence vs. a Neutral-Angry sequence). However, an angry facial expression, for instance, differs from a neutral one at several hierarchical levels: not only at the specific emotion level (angry vs. neutral expression), but also at the valence level (negative vs. neutral valence) and at the emotional arousal level (high vs. low arousal). Accordingly, the emotional PoP effect reported here may rely on memory traces that code for specific emotional expressions, but alternatively on memory traces that code for valence (with similar traces laid down by, say, angry and sad faces) or for arousal level (with similar traces laid down by angry and happy faces). The present data do not allow distinguishing between these different accounts and this issue should therefore be clarified in further research.

Mechanisms Underlying PoP

Intertrial repetition effects are usually interpreted as attentional effects, (e.g., Maljkovic & Nakayama, 1994; Found & Müller, 1996; Wolfe et al., 2003) that is, as occurring early in processing, and reflecting facilitation of the deployment of attention to the objects possessing the repeated attribute. Consistent with this view, evidence from single-cell recordings (e.g., Bichot & Schall, 2002) and brain lesions in monkeys (Walsh, Le Mare, Blaimire, & Cowey, 2000) shows that intertrial priming affects the activity of sensory brain areas. In addition, precuing the location of the upcoming target abolishes the PoP effect, suggesting that attentional factors are important for PoP. However, Huang et al. (2004) recently challenged this view by suggesting that intertrial priming effects occur at a later, post-perceptual stage, and speed response selection (see also Cohen & Magen, 1999, and Mortier, Theeuwes, & Starreveld, 2005 for a similar account of intertrial dimension priming). Support for this response-based account comes from findings showing that PoP was stronger when the response on a given trial was the same as in the previous trial, than when these responses differed (Huang et al., 2004). Yet, it is important to note that the PoP effect remained significant on different-response trials. Thus, it is safe to conclude that response-based mechanisms contribute to, yet do not entirely determine the PoP effect. Finally, a different account, labeled the "ambiguity hypothesis" has recently been put forward against pure attention-related and response-related views. According to this hypothesis, "intertrial priming becomes functional, and therefore measurable, only under circumstances of ambiguity. Ambiguity refers to the presence of uncertainty, conflict, or competition at any level between stimulus and response" (Meeter & Olivers, 2006).

To the extent that the emotional PoP reported here relies on the same mechanism as simple feature PoP, the present findings argue against the ambiguity account of intertrial priming. Indeed, this account predicts that smaller intertrial repetition effects should be found for salient targets (that suffer little from the competition of surrounding distractors) than for less salient targets. In line with previous reports (e.g., Calvo, Avero, & Lundqvist, 2006; Lundqvist & Öhman, 2005), the results from the present study suggest that emotional faces were more salient than neutral faces, as reflected by faster RTs for an emotional target among neutral distractors relative to RTs for a neutral target among emotional distractors. Yet, we report that faces displaying either an angry or a happy expression produced large and reliable intertrial priming effects, whereas faces displaying a neutral expression did not.

A possible resolution of the discrepancy between our findings and the findings on which the ambiguity account relies may reside in the fact that the different conditions of ambiguity were always run in different blocks of trials in Meeter and Olivers' studies (Meeter & Olivers, 2006; Olivers & Meeter, 2006). For instance, PoP in a block of dense-display trials (low-ambiguity condition) was compared to PoP in a block of sparse-display trials (high-ambiguity condition). By contrast, in the present study emotional-target trials (low-ambiguity condition) and neutral-target trials (high-ambiguity condition) were mixed within each block of trials. If the modulation of intertrial repetition effects by ambiguity is indeed contingent on a blocked design, it is reasonable to conclude that such modulation is accounted for by expectation of certain level of ambiguity over a given block of trials, rather than by ambiguity in terms of attentional competition or response selection on a given trial. If so, the ambiguity hypothesis would not pertain to the mechanism underlying intertrial repetition effects but would instead only point to top-down factors that may modulate these effects.

The relative contributions of attention- and response-related factors in the emotional PoP effect should be investigated in further research. An attention-based component of emotional PoP would suggest that emotion repetition further enhances any tendency to attend to a particular emotion. For instance, based on the vast literature suggesting that anxious individuals show an attentional bias toward threat-related stimuli (see Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van Izjendoorn, 2007 for a recent review), one would expect recent encounters with angry faces to exacerbate the bias of anxious individuals. A response-based component of emotional PoP would indicate that the response associated with a recently attended emotional stimulus, whether adaptive or not, is enacted faster or is less subject to inhibition when a stimulus displaying the same emotion must be responded to on a later occasion.

The Face-in-the-Crowd Effect

Our results are also relevant to the literature investigating the role of facial expressions of emotion in visual search performance, also known as the *face-in-the-crowd effect* literature. We used ecologically valid (veridical) faces in a design that made it unlikely that subjects might search for a specific facial expression (mixed-emotional expressions design). We found that both an angry face and a happy face among neutral faces were detected faster than a neutral face among angry faces and happy faces, respectively. Consistent with previous studies (e.g., Fox et al., 2000; Fox & Damjanovic, 2006)[3], we also found that it took longer to produce a negative response when displays contained either only angry faces or only happy faces than when they contained only neutral faces. However, all these effects also occurred with inverted faces. In fact, only the advantage of detecting an angry face relative to a neutral face tended to be larger with upright faces than with inverted faces. Taken together these findings suggest that physical stimulus salience plays an important role in face-in-the-crowd effects measured by overall RT differences for detection of angry and happy faces relative to neutral faces, and that the relatively small contribution of emotional category to search speed might occur only for angry faces (e.g., Fox & Damjanovic, 2006; Hansen & Hansen, 1988).

Conclusion

The present study is the first report of an emotional PoP effect, that is, of faster responses when the same, rather than different, emotional expressions are successively attended. By contrast with detection speed, which (1) was mainly determined by physical stimulus salience and (2) showed a role for emotional category only with threat-related (angry) stimuli and not with positive (happy) stimuli, the emotional PoP effect was found to be exclusively determined by emotional category, and was equally strong for angry and for happy faces. These findings suggest that different aspects of an emotional stimulus give rise to the face-in-the crowd effect and to the emotional PoP effect. The relation between the two phenomena should be further clarified in future research.

[3]By contrast with the present findings, Horstmann and Bauland (2006) found parallel patterns of results on target-present and target-absent trials. Namely, they found faster RTs for Angry-target relative to Happy-target trials on target-present trials and for Angry-crowd relative to Happy-crowd trials on target-absent trials. This difference may result from the fact that these authors used a blocked design, that is, a design in which the emotional expression of the target was known to the subjects in each block), whereas we (as well as other authors who found the same pattern of results as we did, e.g., Fox et al., 2000; Fox & Damjanovic, 2006) used a mixed design, that is., a design in which the emotional expression of the target varying unpredictably from trial to trial. See Lamy et al. (2006) for a detailed description of the differences between mixed and blocked designs in singleton search.

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Received May 2, 2007
Revision received August 16, 2007
Accepted August 28, 2007 ■