Cognition and Emotion

ISSN: 0269-9931 (Print) 1464-0600 (Online) Journal homepage: http://www.tandfonline.com/loi/pcem20

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To cite this article: Daniel Lundqvist, Neil Bruce & Arne Öhman (2015) Finding an emotional face in a crowd: Emotional and perceptual stimulus factors influence visual search efficiency, Cognition and Emotion, 29:4, 621-633, DOI: 10.1080/02699931.2014.927352

To link to this article: http://dx.doi.org/10.1080/02699931.2014.927352

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COGNITION AND EMOTION, 2015
Vol. 29, No. 4, 621–633, http://dx.doi.org/10.1080/02699931.2014.927352

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Finding an emotional face in a crowd: Emotional and perceptual stimulus factors influence visual search efficiency

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In this article, we examine how *emotional* and *perceptual* stimulus factors influence visual search efficiency. In an initial task, we run a visual search task, using a large number of target/distractor emotion combinations. In two subsequent tasks, we then assess measures of perceptual (rated and computational distances) and emotional (rated valence, arousal and potency) stimulus properties. In a series of regression analyses, we then explore the degree to which target salience (the size of target/distractor dissimilarities) on these emotional and perceptual measures predict the outcome on search efficiency measures (response times and accuracy) from the visual search task. The results show that both emotional and perceptual stimulus salience contribute to visual search efficiency. The results show that among the emotional measures, salience on arousal measures was more influential than valence salience. The importance of the arousal factor may be a contributing factor to contradictory history of results within this field.

Keywords: Visual attention; Visual search; Perceptual salience; Arousal; Valence.

For two and a half decades, researchers have examined the influence of emotion on visual attention by using photographs of facial expressions of emotion in visual search experiments (starting with Hansen & Hansen, 1988). This has been a very busy research area, but it is still lacking a consensus regarding *how* and even *if* this type of emotional stimulation influences visual search efficiency. The main reason for this lack of consensus is that through the years, there has been regular reports of a superior detection of angry faces compared to happy faces [the so-called anger superiority effect (ASE); see e.g., Gilboa-Schechtman, Foa, and Amir (1999) and Pitica, Susa, Benga, and Miclea (2012)] mixed with an about equal amount of evidence in the direct opposite direction [the so-called happy superiority effect (HSE); see e.g., Becker, Anderson, Mortensen, Neufeld, and Neel (2011) and Byrne and Eysenck (1995)]. For overviews and further references, see Frischen, Eastwood, and Smilek (2008), Horstmann and Bauland (2006) and Öhman, Juth, and Lundqvist (2010).

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This steady stream of contradictory evidence is of course directly problematic for a claim of an influence of emotion on visual search behaviour, and it becomes even more so when the literature on perceptual influences on visual search efficiency is considered. Results within this field show that the *perceptual salience* (i.e., target/distractor dissimilarity) of a stimulus is closely related to the efficiency by which the target items are detected during the visual search (see e.g., Calvo & Nummenmaa, 2008; cf. Duncan & Humphreys, 1989; Wolfe, 2003). Furthermore, this line of evidence has even been interpreted as a proof that *all* effects on visual attention from facial stimuli stem from perceptual saliency factors (see Calvo & Nummenmaa, 2008).

However, perception and emotion are not mutually exclusive processes, and evidence of an influence from one factor does not necessarily mean that the perceptual salience factor is the only (or even the most influential) factor. Furthermore, this claim has not been explicitly tested as Calvo and Nummenmaa (2008) did not include any measures of *emotional* stimulus factors alongside their measures of perceptual stimulus factors. Indeed, to our knowledge, there is no article where perceptual *and* emotional stimulus properties are assessed and both types of measures are used for prediction of visual search efficiency.

In this article, we present an experiment with the aim of examining *how emotional and perceptual stimulus factors influence and predict search efficiency during a visual search task*. We therefore run an experiment consisting of three different tasks. First, a visual search task is run to collect measures of visual attention search efficiency for a large number of target/distractor combinations (see attention task below). Second, a perceptual discrimination task is run, supplemented with computational stimulus metrics, to collect perceptual salience measures of each target/distractor combination (see perception task below). Third, an emotional stimulus assessment task is run to collect emotional salience measures for each target/distractor combination (see emotion task below). In the analysis, we then examine how these perceptual and emotional stimulus measures may predict the visual attention search efficiency measures.

METHOD

Participants

A total of 20 men and 20 women participated in the experiment (n = 40; 19–29 years; m = 24). These participants were run as two separate groups (each with 10 females and 10 males), one group for each of the two stimulus materials. From previous data from our lab, a group size of 16 or above was estimated as appropriate for reliable item-level data.

Apparatus

The experiment was programmed using Macromedia Director MX 2004 software (Macromedia Inc.), run on a Pentium IV computer, with a 20" CRT (EIZO T965) monitor at a 1600 × 1200 pixels resolution.

Stimulus

The emotional facial stimuli were selected from the Averaged Karolinska Directed Emotional Faces (AKDEF; Lundqvist & Litton, 1998). These stimuli consist of an average male and an average female, each expressing and displaying seven different expressions (afraid, angry, disgusted, happy, neutral, sad and surprised). The peripheral area of all seven expressions was edited to create a uniform background and to limit all between-stimulus variation to the expressive face area (see Figure 1). This was done separately for the averaged male and female stimuli.

Procedure

The participants were tested individually. Each of the tasks was run in the order described below (i.e., attention task, perception task and emotion task). In total, the three different tasks took about 90 minutes to complete. One group of 20 participants (10 females and 10 males) were run

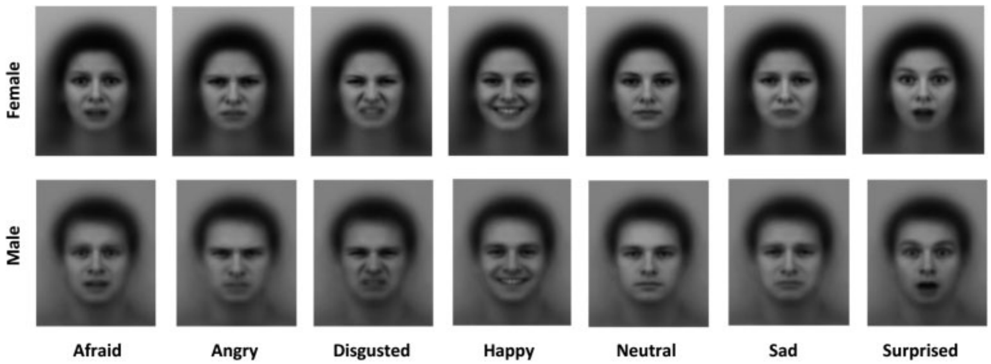

Figure 1. *The facial emotional stimuli used in this experiment. These stimuli were selected from the AKDEF (Lundqvist & Litton, 1998). The peripheral area of all seven stimuli was edited to create a uniform background and to limit all between-stimulus variation to the expressive face area.*

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using the female AKDEF stimuli (see Figure 1), and another identical group of 20 participants using the male stimuli.

Attention task

In the visual search task, all seven emotional expressions (see Figure 1) were used both as targets and as distractors, using all possible target–distractor combinations; in total, there were 42 unique target/distractor combinations. During the visual search task, each stimulus display contained six faces, presented in a circular display (ca 15.4° of the visual field). In half of the stimulus displays (so-called "no-target" conditions), all faces were of the same emotional expression. In the other half (so-called "target present" conditions), one of the six faces was of a different emotional expression from that of the background distractors. A target face could occur at any of the six positions against any of the distractor backgrounds, resulting in a total of 252 (7 distractor emotions × 6 target emotions × 6 positions) different displays containing a target, and seven different display types without target.

Initial self-paced instructions explained that the task was to decide whether all faces in a display were similar (and then the left key should be pressed), or if one face was different from the other (then press the right key). Before the start of the visual search task, the participants were taken through a series of training trial. A trial was initiated by a fixation point presented for one second at the centre of the screen. The stimulus display was then exposed until the participant responded, after which a two-second inter-trial interval was shown before the fixation point reappeared on the screen, initiating a new trial. Each participant was exposed to seven randomly ordered blocks with 72 randomly ordered trials in each block, resulting in a total of 504 trials. In each block, one particular expression (e.g., disgust) was used as distractor, and the remaining six expressions were used as targets. Each block thus contained 72 trials, where 36 trials contained displays with a target present, and 36 trials with no target present. Across the seven blocks, each expression was used as distractor in one block, and as a target in the remaining blocks.

Perception task

Subjective perceptual discrimination task. In the perceptual discrimination task, participants were instructed to judge the physical similarity between a target picture and each of the remaining six comparison expressions. A trial started with a target face (e.g., neutral) being presented at the left of the screen. This target stimulus was presented in the same size as in the attention task, above. The remaining six pictures (e.g., afraid, angry, disgusted, happy, sad and surprised) were placed in random order at the top of the screen. Starting to the right of the target picture,

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running the full width of the screen, a horizontal line was presented. Participants were then asked to place each of the comparison faces at any position along this line, based on the physical similarity between the comparison picture and the target picture. The more similar the comparison picture was to the target face, the closer to the target face it should be placed on the horizontal line. The task was performed by using the computer mouse, by clicking, dragging and dropping the faces at any desired position along the line. Across the seven randomly ordered trials, each picture (afraid, angry, etc.) was presented once as a target picture and in the remaining trials as a comparison picture. Self-paced instructions to the task were presented on the computer screen, followed by a practice trial which presented examples of the stimuli, explained the task and stressed the importance of judging similarity based on the *physical* (and not the emotional) similarity/dissimilarity of the faces. The range of this measure was between 0 and 1.

Computational perceptual salience analysis. As a complement to the subjective perceptual salience measures from the perception task, above, *objective perceptual salience scores* were also assessed, by means of metrics that characterise differences between faces in a quantifiable manner based on the statistical distance between the stimuli. The literature in this area is vast, and the roots of the approach lie in strategies initially developed for the purposes of recognising faces using automated systems in machine vision (Turk & Pentland, 1991). Subsequent efforts in this area have demonstrated broad applicability of these distance measures to problems such as facial recognition (Viola & Jones, 2001), gender and age identification, and also distinguishing between different emotional expressions (Draper, Baek, Bartlett, & Beveridge, 2003). Central to the statistical nature of measuring distances between faces is recognition of the fact that certain regions of the face tend to be strongly consistent across observers in the pixel values that are captured, irrespective of identity or expression. Moreover, there exist statistical correlations among pixels that are also of importance in measuring the statistical distance between faces (e.g., many changes of expression result in a relatively symmetric change in mouth shape across the midline). For a sufficiently large face (in number of pixels), modelling the complete correlation among all pixel values poses a problem that is not feasible from a computational perspective. The significant redundancy among faces makes it possible to transform the raw face data into a space that preserves distances among faces while removing redundancy within the data. Subsequently, one may consider the covariance among pixels that comprise the face within the statistical distance that is considered. The removal of redundancy among the set of raw face examples is performed using principal component analysis (PCA), and the distance among faces computed on the basis of the Mahalanobis distance within this space. The Mahalanobis distance is equivalent to the Euclidean distance among faces, but considers in its determination the covariance among pixels considered. This not only implies a standard distance measure but also accounts for the "normal" variation that exists among faces, providing for a much stronger basis for both discerning between individuals, and also in particular, for characterising differences among facial expressions. Importantly, it has been demonstrated that the characterization of statistical distances among faces subject to PCA and based on a Mahalanobis distances produces the strong correlation with human perceptual judgments of differences among faces (cf. subjective perceptual discrimination task, above) and also significantly outperforms a standard Euclidean distance in this respect (Burton, Bruce, & Hancock, 1999; Burton, Miller, Bruce, Hancock, & Henderson, 2001; Calder, Burton, Miller, Young, & Akamatsu, 2001; Yambor, Draper, & Beveridge, 2002). The precise details of the determination of the *objective perceptual salience scores* appear in the Supplementary Material following the text. These analyses were done separately for the male and female AKDEF stimuli.

Emotional stimulus assessment task

In the emotional assessment task, participants were instructed to rate their emotional impression

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of the different stimuli. During this task, stimuli were presented (in the same size as in the attention and perception tasks, above) one at a time in the upper-middle part of the screen. Below the stimuli, different visual analogue rating scales (VAS) were presented. These scales denoted the three emotional key dimensions of arousal, valence and potency (e.g., Lundqvist, Esteves, & Ohman, 1999, 2004; Osgood, 1966; Russell, 2003). The three VAS for arousal, valence and potency were labelled with an adjective pair for each dimension, one adjective at each end of the scale (e.g., for rated arousal: "Active"—"Passive"; for details of the history of these adjective pairs, see Lundqvist & Ohman, 2005). Participants were instructed to adjust a marker along each of the 10 scales to a position that corresponded to their emotional impression of that particular stimulus. Stimuli were presented in random order, and the order and polarity of all scales were randomly set for each trial. The range of each measure was between 0 and 1.

Data treatment and statistical analysis

Background

As described under stimulus above, the design of the present experiment involved extensive combinations of target and distractor emotions, repeated over two different stimulus materials, collected in two separate groups of participants. The main purpose of this design was to generate a high number of unique target–distractor combinations to enable item-level regression analyses on how attention, perception and emotion measures relate. This design resulted in 42 unique target–distractor emotion combinations per stimulus set (e.g., happy target against neutral distractors, disgusted target against sad distractors, etc.), in a total thus 84 unique item combinations.

Background to the regression analyses. To analyse how measures of emotional and perceptual stimulus factors may predict attention measures, two different types of regression analyses were performed, for two different purposes. First, we wanted to investigate whether *absolute* attention measures [traditional response times (RTs) and accuracy rates] could be predicted by perception and emotion measures. This analysis addresses questions such as whether RTs can be predicted by the perceptual salience and scores on emotional rating scores. Second, we wanted to investigate whether *asymmetries in* attention measures could be predicted by the perception and/or emotion salience measures. The rationale behind this analysis is that the efficiency of target detection during visual search fundamentally depends on how dissimilar the target is to the distractors (see e.g., Duncan & Humphreys, 1989), and an analysis of asymmetries takes these relative target–distractor relationships into account.

About asymmetries. The attention literature has for a long time (see e.g., Treisman & Souther, 1985) documented that the inherent search efficiency of stimulus properties may be revealed in search asymmetries. In short, a search asymmetry is when a target A presented among distractors B is detected differently than when roles are reversed and target B is presented among distractors A. This is relevant in the present article, since from an unbiased perceptual perspective, the RTs and accuracy rates for detection of a target A among distractors B should be the same as that for target B among distractors A. If, by some reason, target A is detected faster and more accurately among B than is B among A (or vice versa), this asymmetry is considered to reflect unequal processing of the two stimuli. In the contemporary attention literature, asymmetries are used to evaluate how stimulus processing is affected by position in the visual field (Karim & Kojima, 2010) and by identification and classification factors (see e.g., Wolfe, 2001). In the present study, we used asymmetries to investigate questions such as whether detection advantages of a stimulus A among B (compared to B among A) in attention measures may be explained by emotional and/or perceptual stimulus differences between A and B.

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General data treatment

To enable the regression analyses, all attention, perception and emotion data were prepared for analysis on an item across condition level. Thus, for all types of data, we calculated scores across participants for each of the 42 stimulus emotion combinations. This procedure was done separately for the female (group 1) and male (group 2) stimulus sets, resulting in 2 × 42 stimulus emotion combinations per measure. This means that although six samples of RT were collected per condition, each RT data point is composed from a total of 120 samples (20 participants × 6 trials per condition). Below, for perceptual as well as for emotional measures, the term "salience" refers to the degree to which the quality of an item (e.g., the perceptual or emotional properties of a target) stands out relative to the quality of comparison items (e.g., the corresponding properties of a distractor).

Attention measures

Data from the visual search task. To create the *absolute attention measures*, average RTs and accuracy data were calculated across participants for each of the 2 × 42 stimulus emotion combinations (e.g., average RTs for target A among distractors B). To create the *relative attention measures*, RT and accuracy scores were calculated for each mirrored stimulus combination as such: [(Target A among Distractors B)–(Target B among Distractors A)]. For instance, RTs for a neutral target among angry distractors minus the RTs for an angry target among neutral distractors.

Perception measures

Subjective perceptual salience. Scores from the subjective perceptual discrimination task were calculated across subjects for each of the 2 × 42 stimulus emotion combinations (target-match; e.g., for a neutral match on an angry target etc.). This was done separately for the two groups and stimulus materials.

Objective perceptual salience. Scores from the image analysis were calculated for each of the 2 × 42 stimulus emotion combinations. Given that there exists one sample for each of the male and female groups that represents the average of faces for each category of expression, the average face images were projected into the reduced dimensionality Principal component space, such that redundancy among individual faces is first removed. Following this, the perceptual salience score for each of the male and female groups was computed according to the Mahalanobis distance between the average faces within the PCA (or Eigenface) space.

Emotion: Data from the emotional rating task. The scores from the three emotional dimensions arousal, valence and potency were prepared for the regression analysis in the following manner: For each of these three dimensions, average absolute rating scores were first calculated across participants separately for each target emotion. Emotional salience scores were then calculated for each of the 42 target–distractor emotion combinations by subtracting the distractor emotion scores from target emotion scores.

RESULTS

In this article, the main aim was to investigate relationships between perceptual and emotional stimulus factors on measures of visual search efficiency. We therefore focus on regression analyses, for examination of how well search efficiency can be predicted by perceptual and emotional measures. However, to provide the reader with a view of the underlying data, a detailed data overview is provided in Table 1. In this table, data are collected at a stimulus item level for all target/distractor combinations, for both attention measures, both perception measures, and all three emotion measures, separately for the two stimulus sets. In Table 1, it can be seen that certain emotions such as happy and surprised are associated with efficient attention (short RTs and high accuracy), high perceptual salience (high discriminability and high computational salience) and high emotional salience (high emotional valence, arousal and potency scores). Conversely, other

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Table 1. *All attention measure (RTs and accuracy), perceptual saliency measures (subjective and computational) and emotional saliency measures (valence, arousal and potency) for all target/distractor emotion combinations, for both of the stimulus sets (female and male AKDEF images)*

				*Distractor/comparison emotion**													
ATTENTION MEASURES				*Female AKDEF stimuli*							*Male AKDEF stimuli*						
Acccuracy	*Emotion*	*Efficiency rank***	*m,%*	*Afr%*	*Ang%*	*Dis%*	*Hap%*	*Neu %*	*Sad%*	*Sur%*	*Afr%*	*Ang%*	*Dis%*	*Hap%*	*Neu%*	*Sad%*	*Sur%*
Target emotion	Afraid	7	87		93	90	93	88	88	73		94	86	90	81	87	76
	Angry	5	89	93		88	93	88	82	90	93		84	93	86	85	90
	Disgusted	3	95	95	97		93	96	96	98	96	92		91	99	93	96
	Happy	2	96	95	98	93		97	98	98	96	99	94		96	98	94
	Neutral	6	88	92	84	93	93		85	93	95	86	94	89		67	88
	Sad	4	90	93	89	91	94	87		90	90	89	92	89	82		89
	Surprised	1	97	93	98	97	98	95	98		95	97	100	97	100	95	
RTs	*Emotion*	*Efficiency rank****	*m, Seconds*	*Afr*	*Ang*	*Dis*	*Hap*	*Neu*	*Sad*	*Sur*	*Afr*	*Ang*	*Dis*	*Hap*	*Neu*	*Sad*	*Sur*
Target emotion	Afraid	4	1.57		1.63	1.59	1.35	1.43	1.49	1.66		1.66	1.66	1.45	1.54	1.74	1.61
	Angry	5	1.65	1.84		1.97	1.42	1.66	1.87	1.41	1.70		1.80	1.38	1.61	1.76	1.32
	Disgusted	3	1.50	1.61	1.55		1.50	1.41	1.56	1.28	1.76	1.66		1.42	1.43	1.54	1.31
	Happy	2	1.42	1.53	1.42	1.59		1.44	1.31	1.23	1.58	1.39	1.51		1.36	1.34	1.29
	Neutral	6	1.66	1.72	1.81	1.59	1.56		1.73	1.47	1.91	1.76	1.50	1.52		1.94	1.38
	Sad	7	1.66	1.80	2.01	1.72	1.50	1.54		1.39	1.80	1.82	1.73	1.46	1.80		1.35
	Surprised	1	1.39	1.80	1.38	1.40	1.22	1.25	1.27		1.80	1.34	1.37	1.30	1.28	1.30	
PERCEPTUAL SALIENCE *Subjective: Discriminability*	*Emotion*	*Saliency rank***	*m, Discriminability*	*Afr*	*Ang*	*Dis*	*Hap*	*Neu*	*Sad*	*Sur*	*Afr*	*Ang*	*Dis*	*Hap*	*Neu*	*Sad*	*Sur*
Target emotion	Afraid	5	.50		.55	.59	.76	.52	.38	.33		.54	.53	.59	.46	.37	.34
	Angry	6	.50	.43		.35	.77	.36	.20	.73	.54		.41	.72	.37	.33	.73
	Disgusted	7	.48	.45	.17		.66	.59	.33	.81	.36	.30		.67	.53	.28	.66
	Happy	1	.54	.54	.65	.55		.36	.59	.64	.34	.59	.60		.41	.52	.65
	Neutral	3	.52	.57	.34	.69	.51		.31	.72	.45	.37	.63	.59		.33	.73
	Sad	2	.52	.46	.32	.56	.71	.37		.80	.42	.43	.63	.60	.22		.73
	Surprised	4	.52	.13	.66	.61	.67	.58	.57		.13	.58	.53	.58	.58	.57	
Objective: Mahalanobis	*Emotion*	*Saliency rank***	*m, Face distance*	*Afr*	*Ang*	*Dis*	*Hap*	*Neu*	*Sad*	*Sur*	*Afr*	*Ang*	*Dis*	*Hap*	*Neu*	*Sad*	*Sur*
Target emotion	Afraid	7	2.53		2.57	2.55	2.83	2.14	1.96	2.01		2.98	2.80	3.00	2.68	2.36	2.52
	Angry	4	2.90	2.57		2.64	3.26	2.57	2.20	3.02	2.98		3.04	3.37	2.95	2.90	3.25
	Disgusted	3	2.93	2.55	2.64		2.96	2.96	2.51	3.09	2.80	3.04		3.30	3.17	2.87	3.32
	Happy	1	3.11	2.83	3.26	2.96		2.86	2.89	3.22	3.00	3.37	3.30		3.17	3.16	3.34

Table 1. (*Continued*)

				*Distractor/comparison emotion**													
				Female AKDEF stimuli							*Male AKDEF stimuli*						
	Emotion	*Efficiency rank***	*m,%*	*Afr%*	*Ang%*	*Dis%*	*Hap%*	*Neu %*	*Sad%*	*Sur%*	*Afr%*	*Ang%*	*Dis%*	*Hap%*	*Neu%*	*Sad%*	*Sur%*
	Neutral	5	2.73	2.14	2.57	2.96	2.86		1.83	2.73	2.68	2.95	3.17	3.17		2.56	3.11
	Sad	6	2.57	1.96	2.20	2.51	2.89	1.83		2.62	2.36	2.90	2.87	3.16	2.56		3.03
	Surprised	2	2.94	2.01	3.02	3.09	3.22	2.73	2.62		2.52	3.25	3.32	3.34	3.11	3.03	
EMOTIONAL SALIENCE																	
Valence																	
	Emotion	*Saliency rank***	*m, VAS-scores*	*Afr*	*Ang*	*Dis*	*Hap*	*Neu*	*Sad*	*Sur*	*Afr*	*Ang*	*Dis*	*Hap*	*Neu*	*Sad*	*Sur*
Target emotion	Afraid	5	−.39		−.20	−.03	−1.41	−.74	−.14	−.79		.26	.22	−1.14	−.35	−.08	−.30
	Angry	6	−.43	.20		.17	−1.22	−.55	.06	−.60	−.26		−.04	−1.40	−.61	−.34	−.56
	Disgusted	7	−.51	.03	−.17		−1.38	−.71	−.11	−.76	−.22	.04		−1.37	−.57	−.30	−.53
	Happy	1	1.10	1.41	1.22	1.38		.67	1.27	.62	1.14	1.40	1.37		.79	1.06	.84
	Neutral	2	.25	.74	.55	.71	−.67		.60	−.05	.35	.61	.57	−.79		.27	.05
	Sad	4	−.26	.14	−.06	.11	−1.27	−.60		−.65	.08	.34	.30	−1.06	−.27		−.22
	Surprised	3	.25	.79	.60	.76	−.62	.05	.65		.30	.56	.53	−.84	−.05	.22	
Arousal																	
	Emotion	*Saliency rank***	*m, VAS-scores*	*Afr*	*Ang*	*Dis*	*Hap*	*Neu*	*Sad*	*Sur*	*Afr*	*Ang*	*Dis*	*Hap*	*Neu*	*Sad*	*Sur*
Target emotion	Afraid	5	−.14		−.19	−.15	−.36	.48	.32	−.34		−.63	−.69	−.64	.47	.16	−.11
	Angry	3	.34	.19		.04	−.17	.67	.51	−.14	.63		−.06	−.01	1.10	.78	.52
	Disgusted	2	.35	.15	−.04		−.21	.63	.47	−.18	.69	.06		.05	1.17	.85	.58
	Happy	1	.44	.36	.17	.21		.83	.67	.02	.64	.01	−.05		1.12	.80	.53
	Neutral	7	−.69	−.48	−.67	−.63	−.83		−.16	−.81	−.47	−1.10	−1.17	−1.12		−.32	−.59
	Sad	6	−.42	−.32	−.51	−.47	−.67	.16		−.65	−.16	−.78	−.85	−.80	.32		−.27
	Surprised	4	.12	.34	.14	.18	−.02	.81	.65		.11	−.52	−.58	−.53	.59	.27	
Potency																	
	Emotion	*Saliency rank***	*m, VAS-scores*	*Afr*	*Ang*	*Dis*	*Hap*	*Neu*	*Sad*	*Sur*	*Afr*	*Ang*	*Dis*	*Hap*	*Neu*	*Sad*	*Sur*
Target emotion	Afraid	6	−.56		−.76	−.64	−.85	−.50	.09	−.50		−.84	−.84	−.94	−.60	−.01	−.34
	Angry	2	.38	.76		.13	−.08	.27	.85	.27	.84		.00	−.10	.24	.83	.50
	Disgusted	3	.30	.64	−.13		−.21	.14	.72	.14	.84	.00		−.10	.23	.83	.50
	Happy	1	.48	.85	.08	.21		.35	.93	.35	.94	.10	.10		.33	.93	.60
	Neutral	4	.08	.50	−.27	−.14	−.35		.58	.00	.60	−.24	−.23	−.33		.60	.27
	Sad	7	−.61	−.09	−.85	−.72	−.93	−.58		−.58	.01	−.83	−.83	−.93	−.60		−.33
	Surprised	5	−.07	.50	−.27	−.14	−.35	.00	.58		.34	−.50	−.50	−.60	−.27	.33	

*For attention measures, this header refers to distractor emotion, i.e., the emotion of the background faces. For perceptual measures, this header refers to the emotion to which the target emotion is compared, either in the subjective task or in the computation of between-face distances. For emotional measures, this header refers to the emotion to which the target is compared.

**The rank score here means that the *highest* score has rank order 1, and so on.

***The rank score here means that the *lowest* score has rank order 1, and so on. This is because the shortest RTs reflect the highest search efficiency.

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Table 2. *Summary of the four significant regression models. On the top rows, the table shows p values and R²'s for the different models. On the below rows, the table then shows β-weights and p values for significant relationships between the independent perception and emotion measures and the dependent attention measures within each model*

	Dependent variables							
	Absolute levels				Asymmetries			
Significant models	*Model 1 RTs*		*Model 2 Accuracy*		*Model 3 RTs*		*Model 4 Accuracy*	
p-value	**		**		**		*	
Adjusted R2	62%		31%		45%		18%	
Independent variables	β-weights	*p*-value	β-weights	*p*-value	β-weights	*p*-value	β-weights	*p*-value
Emotion measures								
Arousal salience	.48	**	.28	*	−.82	**	.27	*
Valence salience			.27	*			.30	*
Potency salience					.50	**		
Perception measures								
Subjective salience	−.64	**	.32	*				
Computaional salience	−.21	*	.28	*				

*$p < .05$; **$p < .0001$.

emotions such as afraid are associated with *in*efficient attention, low perceptual salience and low emotional salience.

Naturally, all effects depend on what target is combined with what distractor, and what the perceptual and emotional dissimilarities between these items are. This is what we target in the regression analysis.

Regression analysis

To investigate the relationships between perceptual and emotional factors on the measures of visual search efficiency, we ran four different multiple regression analyses (best subsets model). The first two analyses focused on predicting *absolute* attention measures, while the other two focused on *asymmetries* in these measures. All four regression models are summarised in Table 2.

Predicting absolute levels of attention data

To analyse the degree to which the different stimulus factors influence the absolute levels of the two attention measures (RTs and accuracy data), two separate regression analyses were run, with either of the two *attention* measures (RTs or accuracy) as the dependent variable, and three *emotional* measures (valence, arousal and potency salience) and two *perceptual* measures (objective and subjective salience) as predictor variables. The results of these analyses are summarised in Table 2.

Model 1: absolute RTs. In the regression analysis (best subsets) of absolute RTs, a significant model with five predictor variables emerged, $F(5, 78) = 28.4$, $p < .000001$, explaining 65% (adjusted $R^2 = .62$) of the variance (see Table 2). The model included one emotional factor: arousal salience ($\beta = -.48$), and two perceptual factors: subjective salience ($\beta = -.64$) and objective salience ($\beta = -.21$). For the *emotional factor*, the direction of the relationships shows that the higher the arousal salience of the target stimuli is (i.e., the larger the difference between a target and the distractors is, in favour of the target), the shorter were the target RTs (i.e., the higher the search efficiency was). Similarly, for the perceptual factors, the direction of the relationship shows that the higher a target's scores are on subjective and objective perceptual salience measures, the shorter were the RTs. Thus, the regression analysis of absolute RTs show that search efficiency in a visual search task is affected by both emotional and perceptual factors and that, for both factors, the more different a target was from the surrounding distractors, the more efficiently it was detected.

Model 2: Absolute accuracy. Regression analysis (best subsets) of absolute accuracy resulted in a significant model with four predictor variables, $F(5, 78) = 8.6$, $p < .00001$, explaining 36% (adjusted $R^2 = .31$) of the variance. The model included arousal salience ($\beta = .28$) and valence salience ($\beta = .27$), as well as both subjective ($\beta = .32$) and objective perceptual salience ($\beta = .28$). For all *emotional and perceptual factors*, the direction of the relationships showed that the larger the salience of the target stimulus, the higher was the response accuracy. Hence, as for RTs, high search efficiency was associated with high emotional and perceptual salience.

Predicting asymmetries in attention data

As above, two separate regression analyses were run for the two attention measures (RT and accuracy asymmetries), again with one of the two *attention* measures (RT or accuracy) as dependent variable at the time, and all three *emotional* measures (valence, arousal and potency salience) and both *perceptual* measures (objective and subjective salience) as predictor variables.

Model 3: RT asymmetries. Regression analysis (best subset) of RT asymmetries resulted in a significant model with two significant predictors, $F(5, 78) = 14.87$, $p < .000001$, explaining 49% (adjusted $R^2 = .45$) of the variance (see Table 2). The model included two emotional factors. Arousal salience ($\beta = -.82$) and potency salience (β = 50). The model included no perceptual factors. The direction of the relationships shows that the larger the AB/BA differences were in arousal salience, the larger the AB/BA asymmetry was on RTs. For instance, a high AB/BA difference in arousal (say for a surprised face among sad distractors compared to a sad target among surprised distractors) means that there is a large AB/BA advantage in RTs for the same condition (i.e., a surprised target is detected a lot faster among sad distractors than vice versa).

For potency, the effect goes in the opposite direction.

Model 4: Accuracy asymmetries. Regression analysis (best subset) of accuracy asymmetries also resulted in a significant model, $F(5, 78) = 4.69$, $p < .0001$, explaining 23% (adjusted $R^2 = .18$) of the variance. The model included two emotional factor, arousal salience ($\beta = .27$) and valence salience ($\beta = .30$); and no perceptual factors. The direction of the relationships shows that the asymmetry is driven by the arousal and valence salience so the larger the AB/BA differences were in arousal and valence salience, the larger the AB/BA asymmetry was on the accuracy measure.

DISCUSSION

In this article, we address the issue of how *emotional* and *perceptual* stimulus factors influence visual search efficiency. Measures of emotional and perceptual stimulus factors were assessed alongside visual attention measures, to analyse the degree to which stimulus salience (target/distractor distances) on these measures may predict the outcome on search efficiency measures (RTs and accuracy) from a visual search task.

Both emotional and perceptual stimulus properties affect visual search efficiency

The results of this experiment show that detection of a target stimulus during a visual search task is strongly influenced by both emotional *and* perceptual factors. For all measures, *target salience is the key*, meaning that *the larger the differences are between a target and the surrounding distractors (on*

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emotional as well as perceptual measures), the more efficiently (faster and more accurately) attention is directed to the target. These results thus show that both emotional and perceptual factors make unique contributions in explaining search efficiency measures from a visual search task.

Perceptual salience

The results show that both subjective and objective measures of perceptual salience have strong and positive relationships to search efficiency measures. Thus, on both measures, high perceptual salience was associated with efficient detection (short RTs and high accuracy rates) during visual search, and vice versa. These relationships closely resemble the results reported by Calvo and Nummenmaa (2008), and are in accordance with the principles regarding target/distractor dissimilarities and search efficiency (i.e., the larger the target/distractor dissimilarities there are, the more efficiently a target is detected) reported in the general the visual attention literature (see e.g., Duncan & Humphreys, 1989; Wolfe, 1998, 2003).

Emotional salience

Similar to perceptual factors, the relationships between measures of emotional salience and visual attention show strong relationships between emotional salience and search efficiency. Thus, the higher a stimulus is rated arousal and valence (relative to the distractors), the more efficiently it is detected. For arousal, the relationship to search efficiency resembles the results reported for schematic facial emotional stimuli by Lundqvist and Ohman (2005). For valence and potency, however, the relationships to search efficiency follow the pattern of an “HSE” and hence are in the opposite direction to that reported by, for instance, Lundqvist and Ohman (2005).

Effects on absolute attention measures and effects on search asymmetries

The above-mentioned relationships between attention measures, perceptual salience and emotional salience are all found both for absolute measures and asymmetry measure. The effects on absolute measures show that target detection is to a very high degree determined by the emotional and perceptual target salience. The effects on asymmetries strengthen another aspect of these findings, showing that not only the difference between targets and distractors matters, but also what matters is which emotion (with which emotional and perceptual properties) is functioning as distractor/background, and which is the deviating target. The results show that (for all measures, except potency), it is the target/distractor difference in favour of the target that matters most. This means that a particular level of emotional and/or perceptual salience has its strongest effect on attention measures when the target stimulus is higher on the emotional and/or perceptual measures compared to the distractor stimuli.

Is arousal (not valence) the main factor for influences on visual search efficiency?

The present experiment shows that the emotional arousal factor has a stronger influence on visual search efficiency measures than what valence has on both absolute measures and asymmetries (see Table 2).

These results are supported by a recently published article from our group (Lundqvist, Juth, & Öhman, 2013). Through an extensive reanalysis of results of 10 years of visual search data from our own laboratory, as well as of data from other researchers over the last two decades, we there showed that the arousal factor systematically and strongly influences the outcome of the reviewed and reanalysed visual search experiments. In that article, results showed that between-expression differences in conveyed emotional arousal systematically influenced visual search results more than the valence of the facial stimulus, so that a happy face higher in arousal than its angry counterpart was likely to be detected with more efficiency (than the angry face) and vice versa (Lundqvist et al., 2013). Further support to the influence of the emotional arousal factor on stimulus processing is found in reviews by Harmon-Jones, Gable, and Price (2012), Lang and

Bradley (2010), Mather and Sutherland (2011) and Phelps and LeDoux (2005) (see Lundqvist et al., 2013 for further references and discussions regarding the role of the arousal factor). From the above analyses, we are however not suggesting that valence does *not* influence, only that the arousal factor appears potentially more influential and deserves being brought to attention.

Limitations

We believe that the unique contribution of this manuscript is that we assess both the emotional and perceptual salience of stimuli, demonstrate an influence of both emotional and perceptual factors on visual search efficiency, and highlight the influence of the arousal factor over that from the valence factor.

However, the main approach used in this experiment, creating a very large number of target/distractor combinations, has some undesired side effects which potentially limits the current results: the large number of trials (504) and the time needed to finish all three tasks (90 minutes) made it difficult to introduce other experimental factors of relevance, such as variation of stimulus material and variation of set size. The fact that we also collapse conditions across subjects in this article also has the side effect that we cannot thereby explore on individual variation in these tasks. The current results rest on the male and female stimuli in AKDEF (Lundqvist & Litton, 1998), and on a fixed set size in the visual search task. In future experiments, the role of these factors deserves being explored further. Finally, we want to make the reader aware of the fact that the objective saliency measure used in this experiment (Mahalanobis) is exceptionally well-suited for identification of relationships between computationally assessed perceptual salience absolute attention measures, but may be less suited for those of our analyses that involve asymmetries (as is also reflected in the outcome of the results from asymmetry analyses).

Manuscript received 24 June 2013
Revised manuscript received 9 March 2014
Manuscript accepted 18 May 2014
First published online 16 June 2014

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SUPPLEMENTARY MATERIAL

Supplementary content is available via the 'Supplementary' tab on the article's online page (http://dx.doi.org/10.1080/02699931.2014.927352).

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