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Arousal and social anxiety but not the emotional category influence visual search performance when using task-irrelevant emotional faces

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ABSTRACT
The goal of the present study was to test the effects of emotional arousal elicited by emotional faces on visual search performance. In Experiment 1, facial expressions acted as distractors presented throughout the task. In Experiment 2, faces were presented only before the task. We found that the level of arousal elicited by faces can better describe their effects on visual search performance compared to their discrete emotional categories. In Exp1, faces with higher arousal ratings were more distracting, possibly because active inhibition is necessary to solve the task. However, in Exp2, higher levels of arousal resulted in better performance, possibly because they activate the arousal system, initiating readiness for action. We also showed that social anxiety diminishes attentional performance due to its influence on executive processing. This does not support the involvement of bottom-up attentional biases in the maintenance of social anxiety that many interventions seem to target.

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Orienting network; executive attention; number matrix; attentional biases; valence; intensity

Introduction

From an evolutionary perspective, faces are highlighted objects of perception, as they may hold vital cues about social behaviors such as identification and recognition of individuals, assessing trustworthiness, in- and out-group membership, and establishing and maintaining social dominance (Behrmann & Avidan, 2022; Coelho et al., 2010; Kovács-Bálint et al., 2013). In fact, the visual perceptual system is thought to be hard-wired to detect human faces (Csibra et al., 2004; Grill-Spector et al., 2004; Grossmann et al., 2007; Leppänen et al., 2007; Stefanics et al., 2012). Furthermore, emotionally charged stimuli (such as faces with emotional expressions) are prioritized over neutral stimuli in visual processing (Hedger et al., 2016; Niu et al., 2012; Pilarczyk & Kuniecki, 2014; Schupp et al., 2006) because they signal cues that are key for our survival, e.g., defense, food, and reproduction (Cacioppo et al., 1999; Vuilleumier, 2015). They are thought to be processed via survival circuits in the brain that are the result of evolutionary adaptations (LeDoux, 2012, 2022). As a result, emotionally charged objects (including emotional faces) are detected faster and tend to hold attention for a longer time than neutral ones (Fox et al., 2001; Frischen et al., 2008; Mulckhuyse, 2018). These attentional biases were often at the center of interest in studies using emotional faces, as they may serve as the basis of the acquisition and maintenance of social anxiety disorder (Eysenck & Calvo, 1992; Mogg & Bradley, 2002; Schofield et al., 2013) but can also be targeted in interventions to reduce fear and symptoms of anxiety (Heeren, Mogoaşe, McNally, et al., 2015; Neubauer et al., 2013; Price et al., 2011). However, a previous meta-analytic study (Heeren, Mogoaşe, Philippot, et al., 2015) argues that a reconsideration of the role of attentional biases in the conceptualization of social anxiety is due, also noting that previous studies might have been insufficiently reliable to measure them.

Although a large number of past studies have investigated the influence of facial expressions of emotions on visual attention in the past three and a half decades, the field still lacks a consensus on exactly how this occurs. The first study to explore

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the influence of emotional faces on visual search efficiency (Hansen & Hansen, 1988) used the face-in-the-crowd paradigm, where participants searched for discrepant facial expressions among nine faces. In half of the trials, the crowd consists of eight faces that depict various individuals but have the same expression (e.g., neutral) and one target face that holds a different expression (e.g., angry). In the other half of the trials, all nine faces had the same expression. Participants needed to indicate if they saw a target face or if all expressions were the same. This study coined the anger superiority effect, that is, faces with angry expressions are found faster than any other emotional category because they are signals of a direct threat. More recent studies claim that this effect is even more pronounced in people with social anxiety, as they tend to fixate quicker on threats and have difficulty disengaging from them (Capriola-Hall et al., 2021; Mogg & Bradley, 2002). A vast number of studies followed the initial one by Hansen and Hansen using the same or a similar paradigm, but the results are mixed to date, as some of these studies replicated the results (Kennett & Wallis, 2019; LoBue et al., 2014; Lundqvist et al., 1999; Rosset et al., 2011; Sawada, Sato, Kochiyama, et al., 2014) while a number of them did not (Becker et al., 2011; Coelho et al., 2010; Craig et al., 2014; Nummenmaa & Calvo, 2015; Zsido, Arato, et al., 2021). A possible solution to the mixed results could be to interpret emotional expressions in the framework provided by the dimensional emotion theory (Reisenzein, 1994; Russell & Mehrabian, 1977). That is, defining them alongside emotional dimensions (i.e., valence, arousal) instead of using discrete categories (e.g., happy, angry).

The arousal level elicited by images of emotional facial expressions seems to be the factor that mostly affects visual search performance and consequently may help to explain the contradictory results. The first studies (Lundqvist et al., 2014, 2015) that sought to explore *whether* and *how* arousal elicited by emotional faces affects visual search performance reanalyzed the data from past experiments conducted in their laboratory. Here, the classical face-in-the-crowd paradigm was used, while emotional ratings (intensity and arousal) were borrowed from a validation study of the face database (Goeleven et al., 2008). The results showed that higher arousal ratings (and greater arousal differences between the target face and the crowd) resulted in shorter reaction times for finding the target, regardless of the facial expression. This effect seems more consensual, although less often investigated, among past studies compared to the results regarding the superiority of a discrete emotional category (Saito et al., 2021; Sawada, Sato, Uono, et al., 2014; Sawada & Sato, 2015; Svärd et al., 2014). The relatively low number of studies is striking in light of the vast amount of previous studies available on the effect of arousal with types of stimuli other than faces (Leclerc & Kensinger, 2008; Mather & Sutherland, 2011; Sutton & Lutz, 2019; Zsido, 2023; Zsido et al., 2018, 2019, 2020). Although a recent study (Vogt et al., 2022) examined the goal-relevance in social anxiety on a dot-probe task using angry faces and neutral houses, to date, we found no studies investigating the role of emotional arousal conveyed by emotional faces in social anxiety.

Furthermore, past studies using emotional faces mainly focused on the role of arousal and did not test the influence of valence. We found only one study showing (Dodd et al., 2017) an anxiety-linked bias for angry over happy faces when the emotional faces were task-irrelevant. This is a justifiable omission only if the processing of emotional arousal precedes that of its valence (Cuthbert et al., 2000; Recio et al., 2014). While the result of some studies utilizing ERP methodology reported valence effects at very early EEG components suggesting the opposite (Olofsson et al., 2008), as attention is captured by negative stimuli earlier than positive ones(Carretié et al., 2004), the results are inconsistent (Olofsson et al., 2008). In contrast, a number of studies suggest that (stimulus) saliency is driven by arousal, not valence (Liddell et al., 2005; Sutherland & Mather, 2018; Touroutoglou et al., 2014; Zsido, 2023), and because of that arousal triggers the amygdala's activation irrespective of whether it stems from positive or negative valence (Anderson et al., 2003; Kensinger & Schacter, 2006; Mather & Sutherland, 2011; Pessoa & Adolphs, 2010). However, as it was not shown that valence is not correlated with behavioral outcomes, clarification of its role in addition to arousal is necessary.

It remains unclear how emotional faces affect the top-down attentional process, although the effects of exogenous attention to emotional distractors (Carretié et al., 2004). The answer to this may lie in the way in which these stimuli are presented. While *task-*

relevant emotional objects typically result in better task performance (Purkis & Lipp, 2007; Sander et al., 2003), the roles of involuntary (bottom-up) and voluntary (top-down) processes are difficult to disentangle because they produce the same outcome. However, in cases in which emotionally charged stimuli are *not relevant* to the task (i.e., they are task-irrelevant distractors), their effects may be explored to a deeper level. In fact, these stimuli can be presented in several ways to make them irrelevant to the task; the most commonly used method is to present them as distractors during the task. Past studies that utilized this presentation method have shown that active inhibition is necessary to avoid looking at them (Burra et al., 2017; Melloni et al., 2012; Xu et al., 2023), resulting in diminished performance on the primary task (Heim & Keil, 2019; Ortner et al., 2013; Plass & Kalyuga, 2019; Schupp et al., 2007). Even more intriguing is the fact that since emotional content is processed automatically (Vuilleumier, 2015), it can still activate the arousal system (LeDoux, 2012) to initiate readiness for action (Olofsson et al., 2008; Pessoa, 2013) before being suppressed (Burra et al., 2019) or the attention reoriented to the target (Carretié et al., 2004; Chelazzi et al., 2019). In fact, it has been shown that the emotional content of unattended faces presented at the periphery is rapidly processed (Stefanics et al., 2012). Consequently, emotional faces, if used as task-irrelevant distractors presented during the task, can impair task performance (Rigoulot et al., 2011, 2012). This can especially be true for individuals prone to social anxiety, as it has been shown that they have issues with attentional control (Shi et al., 2019). Indeed, it has been shown that threatening stimuli can cause prolonged disruption to goal-directed attention in anxious individuals (Raeder et al., 2019).

However, task-irrelevant stimuli can be used as distractors that precede the task (as they are only displayed at the onset of the task). Previous studies using facial (Dennis & Chen, 2007; O'Toole et al., 2011) and other types of emotionally charged stimuli (Hamamouche et al., 2017; Phelps et al., 2006; Zsido et al., 2020) have shown that such distractors can enhance performance when presented immediately prior to the task. This is consistent with the dual competition framework (Pessoa, 2009, 2013), which posits that emotionally charged stimuli can enhance subsequent attentional performance. That is, the higher level of activation elicited by arousing stimuli may have a positive effect on task performance because it triggers a vigilant information-gathering mode (Mather et al., 2015; Pessoa, 2009; Zsido et al., 2020). In contrast, anxious individuals have difficulty disengaging their attention from irrelevant threat-relevant information, even when it is presented dissociated from the task (Becker et al., 2019; Zsido et al., 2020), potentially leading to disruptions that persist during the task, resulting in impaired performance. Facial emotional stimuli could be misinterpreted by socially anxious individuals (Chen et al., 2020; Schofield et al., 2007), who tend to perceive other expressions as negative toward themselves (e.g., happy – ridiculous, sad – disappointing, or even neutral expressions as angry), not just those showing anger (Chen et al., 2020; Mohlman et al., 2007). Since the expected effect of task-irrelevant stimuli might differ depending on when they are presented, here we sought to test the effects of emotional faces presented as distractors during and before a visual search task in two separate experiments.

Our overarching goal was to test the effects of emotional arousal elicited by task-irrelevant emotional facial expressions on visual search performance. In Experiment 1, the emotional stimuli acted as distractors that were present throughout the whole visual task. In Experiment 2, while emotional stimuli were still task-irrelevant, they were presented immediately before the visual task. In both experiments, our research question was whether categorical emotions or emotional dimensions provide a better understanding of how emotions affect visual search performance. We hypothesized that we would find an effect of arousal, but not of emotional category, across two experiments. In Experiment 1, we expected that higher levels of arousal would decrease performance as the processing of task-irrelevant distractors would need to be inhibited. Here, we also tested the effect of valence but did not expect it to be a significant predictor of performance. In Experiment 2, we hypothesized that arousal would increase performance (contrary to Exp1) because participants would not need to suppress it. Furthermore, we sought to test the effects of social anxiety. This was necessary because past studies using emotionally charged stimuli have shown that attentional biases are more pronounced in individuals with higher levels of anxiety or phobia (Abado et al., 2021; Cisler et al., 2007; Cisler & Koster, 2010; Mogg & Bradley, 2002; Schofield et al., 2013). Based on past results with other types of stimuli than faces, we expected that the effect of arousal in both experiments would be more pronounced for more socially anxious participants.

Experiment 1 – Emotional faces presented during task

Methods

Participants

We conducted an a priori power analysis using the pwr package for R (Champely et al., 2018; R Core Team, 2020) to test for a general linear model with a five-level repeated factor and one covariate with a conservative approach ($f = 0.25$, $1\text{-}\beta = 0.95$) considering the results of previous studies (Zsido et al., 2018). The required minimum sample size was 20. To confirm that the sample size based on GLM would be appropriate for interpreting the main results through GLMM we ran a simulation using the simr package for R (Green & Macleod, 2016) for a mixed model with three predictors. Here, the required minimum sample size was 27. We collected data in weekly increments with the goal of ending data collection after the week the required sample size was met. We collected data from 30 volunteers (16 females) who were undergraduate students at the university in which the data were collected. Their mean age was 21.4 (SD = 1.50). Data from two participants were excluded because of failure to follow instructions.

All participants were right-handed and reported normal or corrected-to-normal vision. Our research was approved by the Hungarian United Ethical Review Committee for Research in Psychology (approval number 2019-109) and was carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki). All participants provided written informed consent. The study was preregistered at OSF (https://osf.io/ubx8c). We did not deviate from the preregistered plan.

Questionnaire

Participants completed the 6-item short forms of the Social Interaction Anxiety and the Social Phobia Scales (Peters et al., 2012; Zsido, Varadi-Borbas, et al., 2021). The scales measure general anxiety associated with the initiation and maintenance of social interactions and the experience of anxiety associated with the performance of various tasks while being scrutinized by others. Items are rated on a 5-point Likert-type scale with values ranging from 0 “Not at all characteristic or true of me” to 4 “Extremely characteristic or true of me”. That is total score ranges from 0 to 48. The scales have excellent psychometric properties. We used the total sum scores of the two scales; higher scores indicate higher levels of social anxiety. The mean score of the Experiment 1 sample was 12.3 (SD = 7.23) with a minimum score of 0 and a maximum score of 27. As a comparison, in the Hungarian validation study (Zsido, Varadi-Borbas, et al., 2021) the mean score of the adult community sample was 10.41 (SD = 5.31) and mean score of the clinical sample was 20.94 (SD = 5.48).

Stimuli and design

The facial stimuli were selected from the Averaged Karolinska Directed Emotional Faces (Lundqvist & Litton, 1998). The stimuli set consists of an average male and an average female expressing different expressions. We used the male and female versions of five expressions (afraid, angry, happy, neutral, and sad), resulting in 10 pictures in total. In line with past studies (Lundqvist et al., 2014, 2015), we sought ratings of these pictures on dimensional emotional variables. At the end of the testing session, participants were asked to rate the arousal level and valence of each picture using 5-point Likert-type scales (1 – low arousal/negative valence to 5 – high arousal/positive valence). Table 1 shows the means and standard deviations of the ratings. These pictures served as task-irrelevant distractor *background* images during the visual search task. See Figure 1 for the trial structure.

Table 1. The central tendencies of the ratings of the facial stimuli used in Experiment 1.

	Valence		Arousal	
Facial expression	Mean	SD	Mean	SD
Happy	4.37	0.642	3.40	0.855
Angry	1.60	0.736	3.60	0.770
Fearful	2.48	0.482	3.25	0.612
Neutral	2.88	0.468	2.45	0.824
Sad	1.82	0.464	3.03	0.830

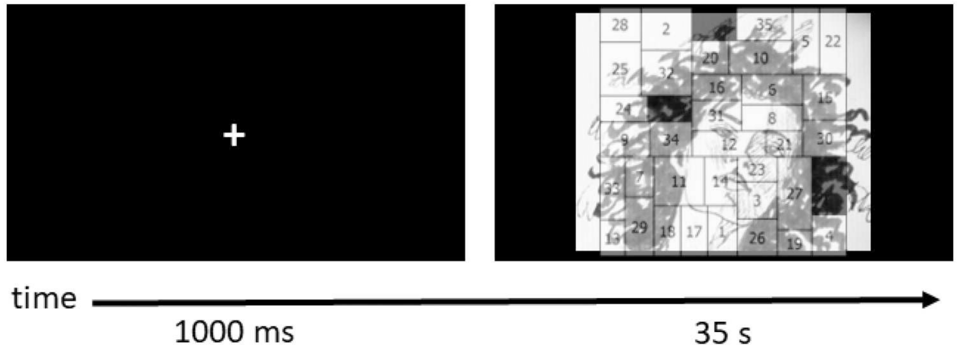

Figure 1. Trial structure of the number-finding task. In Experiment 1, each trial started with a fixation cross followed by a number matrix with a background of an average face. Please note that in the examples shown, we replaced the AKDEF and KDEF pictures due to copyright regulations. The picture we used was retrieved from https://unsplash.com/ and is the work of Maria Lupan.

The visual search task consisted of searching for numbers (sequentially) in matrices that were created using a special matrix generator program. The size of the matrices was 700 × 700 pixels (17.55° × 17.55°). Each matrix contained 35 white rectangles (with numbers) – the width and height of these varied from 150 to 300 pixels (visual angle of 3.79° to 7.57°) – and 3–6 black ones (without numbers). The black rectangles were randomly distributed among the white ones and were added simply to maintain the same overall global shape in the search area. The width and height of the black rectangles varied from 70 to 230 pixels (visual angle of 1.51° to 4.98°). Both the matrices and rectangles within had a 2-pt black border drawn around them. The numbers ranged from 1 to 35 and were randomly distributed among the rectangles. Each number appeared only once in a given matrix. All the rectangles contained a number printed in black in 32-pt Tahoma font. In each trial, a number matrix was superimposed on a facial image.

We utilized the number matrix paradigm (Zsido, Stecina, et al., 2021) in this study because finding number 1 primarily requires attention orienting as it is a simple visual search task where the participant is looking for a target guided by visual features. It relies comparatively more on bottom-up than top-down processing because the primary determinant of behavior is the difference in appearance between the number one and the other distractor numbers in the array. However, the task of searching through the number array (i.e., from number 1–10) relies more on top-down than bottom-up processing because searching through the rest of the numbers requires the participants to control their attention and constantly maintain their search target and update the information in working memory each time a new target digit is found.

The experiment consisted of 60 trials in total, and the trials included a 2 (face gender: male, female) × 5 (emotion: afraid, angry, happy, neutral, and sad) factorial design with 6 repetitions. The number matrices used were randomized across participants and trials. The testing session lasted approximately 40 min.

Apparatus and procedure

The stimuli appeared on a 17-inch LCD Touchscreen color monitor with a resolution of 1366×768, refresh rate and sampling rate of 60 Hz, and 24-bit color format. We used PsychoPy Software v3.0 for Windows (Peirce, 2007) to present the stimuli and to collect responses from participants.

Data were collected individually in a dim and quiet room. Participants were seated at a distance of approximately 60 cm from the monitor. Participants received both oral and written task instructions. First, they completed the practice trials (with the scattered versions of the two neutral face images in the background), after which they were given an opportunity to ask questions. If they indicated that they understood the task fully, the experiment began. Each trial started with a white fixation cross presented for 1000 ms on a black background. Then, the number matrix appeared in the center of the screen simultaneously with an image in the background; the display not filled by the matrix/image was black. The participants' task was to locate the numbers in ascending order starting with the number one and to indicate each find by clicking on the numbers by touching them on the screen. They were instructed to try and complete the task as quickly and accurately as possible. The number matrix was presented for 35 s. Each new trial was initiated by the participant by pressing the spacebar, therefore they had the opportunity to rest or take a break if they felt it necessary.

Statistical analysis

Statistical analyses were performed using the JAMOVI Statistics Program version 2.3 for Windows (Jamovi Project, 2022). Visual search performance was indexed by *counting score*, i.e., the highest number reached during the visual search in the number matrix (Zsido et al., 2018).[1] We first identified outlier trials, defined as those greater than ±2.5 standard deviations of the group mean (resulting in the removal of less than 1% of all the collected data) in each trial for each subject. We then checked to ensure that the distribution of the variables did not deviate significantly from a normal distribution (Shapiro-Wilk *ps* > .05).

According to the preregistered analysis plan (https://osf.io/ubx8c), first, we carried out a GLM analysis with counting score as the dependent variable and facial expression (neutral, sad, fearful, happy, angry) as a repeated measures factor and social anxiety score as a covariate. We also performed Bayesian analyses to quantify the evidence for the absence of effects.[2] Then, we performed a GLMM with counting score as the dependent variable, arousal, valence, and social anxiety as independent predictors, and the discrete emotional category as a random coefficient. Intraclass correlation coefficients were <.001 and the Random Effects Likelihood Ratio Test was not significant in all models, meaning that observations within clusters are no more similar than observations from different clusters. Effect sizes are presented as partial eta squared (η_p^2) for the GLMs. Tukey corrections were used to account for multiple comparisons.

Results

We began by testing the effect of the emotional category of task-irrelevant emotional expressions on search performance and whether social anxiety affects this effect. The statistical results are presented in Table 2, and descriptive statistics can be found in Supplementary material 1. As Figure 2 shows, the main effect of facial expression was not significant. The main effect of social anxiety and the interaction between the two

Table 2. Results of the GLM analysis with counting score as the dependent variable.

		df	F	p	η_p^2	BF01
Counting score	Facial expression	4, 112	0.508	0.730	0.018	10.810
	Social anxiety	1, 28	2.25	0.145	0.074	1.064
	Interaction	4, 112	0.580	0.678	0.020	11.604

independent predictors were nonsignificant. In line with our hypothesis, we did not find any effect of discrete emotions on visual search performance.

Then, we tested whether more negative valence and higher arousal ratings elicited by the faces (regardless of emotional category) would result in a greater decrease in search performance and whether this effect would be more pronounced in socially anxious individuals. The statistical results are presented in Table 3. We found that the counting score was lower when the task-irrelevant picture was more arousing but was independent of the valence rating. We also found a performance decrement in more socially anxious individuals. As shown in Figure 3, there was no interaction between arousal and social anxiety. In line with our expectations, higher arousal and higher levels of social anxiety resulted in decreased search performance. However, we did not find a valence effect, and the effect of arousal was similar across social anxiety levels.

Discussion

In Experiment 1, we investigated how task-irrelevant emotional faces that were present throughout the

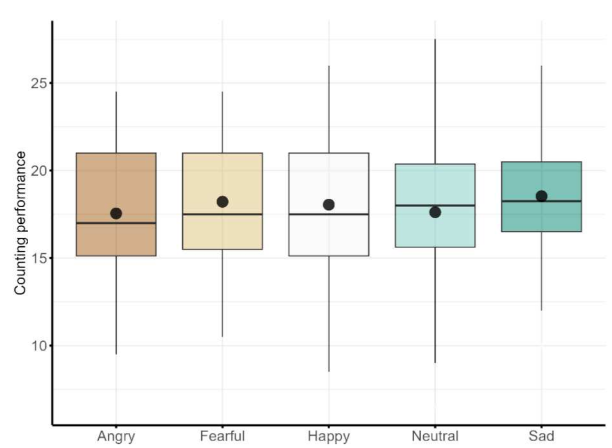

Figure 2. Search performance as indicated by the highest number reached (counting performance). Findings are presented across distractor emotions. Black dots show the means of the variables.

Table 3. Results of the GLMM with counting score as the dependent variable and arousal and valence ratings and social anxiety as independent predictors.

		df	*F*	*p*	*β*
Counting score	Arousal	1, 142	5.48	0.021	−.200
	Valence	1, 142	0.35	0.558	−0.054
	Social anxiety	1, 142	4.60	0.034	−.179
	Arousal x Valence	1, 142	0.53	0.470	0.061
	Arousal x Social anxiety	1, 142	1.88	0.173	−.111
	Valence x Social anxiety	1, 142	0.59	0.445	−0.07
	Arousal x Valence x Social anxiety	1, 142	1.17	0.282	0.095

whole visual task affected visual search performance. Our research question was whether categorical emotions or emotional dimensions provide a better understanding of how emotions affect visual search performance. Our results confirmed our hypothesis; that is, we found an effect of arousal but not an effect of emotional category. As expected, task-irrelevant emotional faces (regardless of emotional category) interfered with task performance only at higher levels of arousal, resulting in lower counting scores. This is in line with the results of past studies with emotional faces (Rigoulot et al., 2011, 2012) and other types of emotionally charged stimuli – such as pictures of injuries or scenes of accidents (Ortner et al., 2013), scenes of erotica, adventure and sports or scenes of mutilations, threat, and violence (Schupp et al., 2007), or high-arousing sounds (scream, attack, baby cry) (Heim & Keil, 2019) – that high-arousing task-irrelevant stimuli were associated with poorer performance on the task (compared to trials low-arousing distractors). It has been argued that since emotional content is processed automatically (Stefanics et al., 2012; Vuilleumier, 2015), it can still activate the arousal system (LeDoux, 2012), and active inhibition is necessary to avoid looking at them (Burra et al., 2017; Melloni et al., 2012; Xu et al., 2023). In fact, it has been shown that the emotional content of unattended faces presented at the periphery is rapidly processed. A novelty of our experiment is that we did not find an effect of valence. While this does not prove that it does not affect visual search performance, this is still an important first step toward the clarification of its role besides arousal and even to prove that valence is not correlated with behavioral outcomes.

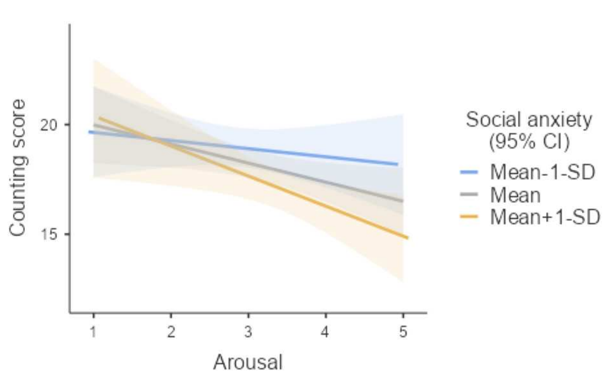

Figure 3. The relationship between search performance (indicated by counting score) and arousal at various levels of social anxiety.

Furthermore, another novelty of our results is that higher levels of social anxiety resulted in worse performance; however, we did not find an interaction with arousal. On the one hand, the main effect could mean that there are more fundamental biases at play in facial information processing in social anxiety (Machado-de-Sousa et al., 2010) with altered neural response to face compared to nonanxious individuals (Gentili et al., 2016) that happen regardless of facial expressions (Philippot & Douilliez, 2005). The lack of interaction with arousal is in line with past findings suggesting that attentional biases can be observed in nonclinical populations with low levels of (general and specific) anxiety (Armstrong et al., 2013; Hindi Attar et al., 2010; Mogg et al., 1997).

Experiment 2 – Emotional faces presented preceding the task

Methods

Differences from Experiment 1

While Experiment 1 was successful in addressing our hypothesis, we identified two limitations that we decided to address in Experiment 2. The first limitation is the relatively low number of individual images used as emotional stimuli (i.e., 10 faces). Therefore, we decided to use a larger number of facial stimuli, which was only possible by switching to individual faces from averaged faces. Relatedly, we increased the number of trials to increase the power of our experiment (Baker et al., 2021) and to reduce the noise introduced by the low-level visual differences between the individual images. To maximize the number of trials within an emotional category per participant and because we did not find a significant effect for the category, we decided to use only four categories instead of five. We decided to drop the sad category, as contrary to the other three emotional faces, past studies did not find any effect with it (Frischen et al., 2008; Williams et al., 2005). Further, sad expression is linked to the inhibition of aggression instead of signaling danger such as anger and fear, and is generally associated with lower levels of arousal (Blair et al., 1999). The second limitation of Experiment 1 was that we only recorded the last number found in the number matrix as an indicator of task performance. While this is a justified method used in past experiments (Zsido et al., 2018), we wanted to assess outcomes that are more fine-grained and, thus, may be more sensitive to the effects of the stimuli used. Furthermore, we wanted to measure a variable that is more reflective of the involuntary processes of attention (i.e., the time to find the first number in the matrix) in addition to a variable that is influenced more by voluntary processes and could be reflective of executive attention (i.e., the time of finding the first ten numbers). This also makes our results comparable with a larger number of our previous studies using the same paradigm (Zsido et al., 2020, 2022; Zsido, Stecina, et al., 2021).

Participants

We conducted an a priori power analysis using the pwr package for R (Champely et al., 2018; R Core Team, 2020) to test for a general linear model with a four-level repeated factor and one covariate with a conservative approach ($f = 0.25$, $1\text{-}\beta = 0.95$) considering the results of Experiment 1 and based on the results of a previous study using a similar paradigm (Zsido et al., 2020). The required minimum sample size was 32. To confirm that the sample size based on GLM would be appropriate for interpreting the main results through GLMM we ran a simulation using the simr package for R (Green & Macleod, 2016) for a mixed model with three predictors. Here, the required minimum sample size was 38. We collected data in weekly increments with a goal to end data collection after the week the required sample size was met. We collected data from 42 volunteers (25 females) who were undergraduate students at the university in which the data were collected. Their mean age was 22.5 ($SD = 3.13$). Data from one participant were excluded because of failure to follow instructions.

All participants were right-handed and reported normal or corrected-to-normal vision. Our research was approved by the Hungarian United Ethical Review Committee for Research in Psychology (approval number 2019-109) and was carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki). All participants provided written informed consent. The study was preregistered at OSF (https://osf.io/y7fch). We did not deviate from the preregistered plan.

Questionnaire

Similar to Experiment 1, we used the Social Interaction Anxiety and the Social Phobia Scales to measure participants' social anxiety. The mean score of the Experiment 2 sample was 8.89 ($SD = 6.64$) with a minimum score of 0 and a maximum score of 27.

Stimuli and design

The facial stimuli were selected from the Karolinska Directed Emotional Faces (Lundqvist et al., 1998). The stimuli set consisted of 35 male and 35 female amateur actors expressing different facial expressions. We used all male and female versions of four expressions (afraid, angry, happy, and neutral), resulting in a total of 280 pictures. A validation study (Goeleven et al., 2008) provided ratings of the faces on intensity and arousal using 9-point Likert-type scales (1 – low intensity/arousal to 9 – high intensity/arousal) on a larger pool of participants. Table 4 shows the means and standard deviations of the ratings. These pictures served as task-irrelevant

Table 4. The central tendencies of the ratings of the facial stimuli used in Experiment 2.

	Intensity		Arousal	
Facial expression	Mean	SD	Mean	SD
Fearful	6.15	0.677	3.87	0.389
Angry	6.40	0.641	3.75	0.565
Happy	6.74	0.369	4.00	0.333
Neutral	5.29	0.343	2.47	0.191

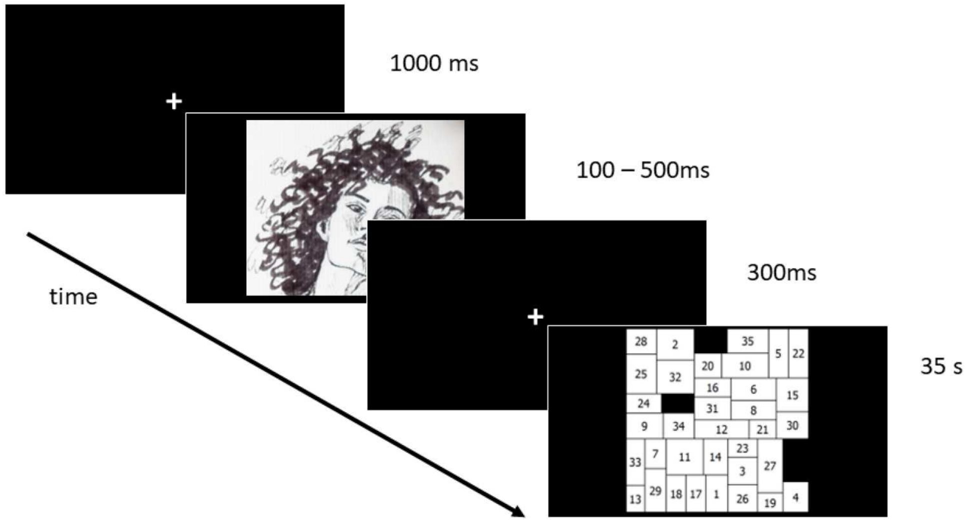

Figure 4. Trial structure of the number-finding task. In Experiment 2, the fixation cross was followed by a priming stimulus (individual face). Then, a fixation cross was presented again followed by a number matrix. Please note that in the examples shown, we replaced the AKDEF and KDEF pictures due to copyright regulations. The picture we used was retrieved from https://unsplash.com/ and is the work of Maria Lupan.

distractor *priming* images appearing before the visual search task. See Figure 4 for the trial structure.

The visual search task consisted of the same number of matrices used in Experiment 1. The experiment consisted of 96 trials in total, and the trials included a 2 (face gender: male, female) by 4 (emotion: afraid, angry, happy, and neutral) factorial design with 12 repetitions. The facial stimuli were counterbalanced across participants, with each facial expression appearing with approximately the same probability across all participants. The number matrices used were randomized across participants and trials. The testing session lasted approximately 60 min.

Apparatus and procedure

The presentation of stimuli and data collection were identical to those in Experiment 1. The only exception was that each trial started with a white fixation cross presented for 1000 ms on a black background. Then, a facial stimulus appeared in the center of the screen for a short duration (100, 300, or 500 ms randomized across trials to prevent the anticipation of the start of the task). After the facial stimulus, a white fixation cross was presented for 200 ms on a black background, which was immediately followed by the number matrix task appearing in the center of the screen; the display not filled by the matrix was black. Each new trial was initiated by the participant by pressing the spacebar, therefore they had the opportunity to rest or take a break if they felt it necessary.

Statistical analysis

Statistical analyses were performed using the JAMOVI Statistics Program version 2.3 for Windows (Jamovi Project, 2022). Our behavioral measures included examining the RTs (in seconds) for the time needed to find Number 1 and the total search time (in seconds) for finding Numbers 1 through 10 based on previous studies using the same paradigm (Zsido et al., 2020, 2022). We first identified and removed outlier trials, defined as those greater than ±2.5 standard deviations of the group mean (resulting in the removal of less than 1% of all the collected data) in each trial for each subject. We then checked to ensure that the distribution of the variables did not deviate significantly from a normal distribution (Shapiro-Wilk $ps>.05$).

According to the preregistered analysis plan (https://osf.io/y7fch), first, we carried out two GLM analyses with RTs for finding number 1 and total search times as the dependent variable (respectively) and facial expression (neutral, fearful, happy, angry) as repeated measures factor and social anxiety score as a covariate. Then, we performed two GLMMs with RTs for finding number 1 and total search times as the dependent variable (respectively) as the dependent variable, arousal, intensity, and social anxiety as independent predictors, and the discrete emotional category as a random coefficient. Effect sizes are presented as partial eta squared (η_p^2) for the GLMs. Tukey corrections were used to account for multiple comparisons.

Results

First, we tested the effect of the emotional category of facial expressions as priming stimuli on search performance and whether social anxiety affects this effect. We carried out two GLM analyses with RTs for finding the first number and overall search performance (respectively) as dependent variables and facial expression (neutral, fearful, happy, angry) as repeated measures factor and social anxiety score as a covariate. The statistical results are presented in Table 5. As Figure 5 shows, the main effect of emotion was not significant for either finding the first number or overall search performance. The main effect of social anxiety and the interaction was also nonsignificant for both measures. That is, contrary to our hypothesis, we did not find any effect of discrete emotions on visual search performance.

Then, we tested whether higher arousal ratings elicited by the faces (regardless of emotional category) would result in better search performance and reduce the performance of socially anxious individuals. The statistical results are presented in Table 6, and descriptive statistics can be found in Supplementary material 1. We found that the arousal of the task-irrelevant pictures was a significant negative predictor of the time to find the first number, while social anxiety was a significant positive predictor of search time. As Figure 6 shows, there was no interaction between arousal and social anxiety. In contrast to our hypothesis, higher arousal levels resulted in faster search performance in the short term. However, higher levels of social anxiety increased the overall search times.

Discussion

In Experiment 2, we investigated how task-irrelevant emotional faces presented immediately before the visual task affected visual search performance. Our research question was whether categorical emotions or emotional dimensions provide a better

Table 5. Results of the GLM analyses with finding the first number and overall research performance as the dependent variable.

		df	*F*	*p*	η_p^2	BF_{01}
Finding number 1	Facial expression	3, 120	2.419	0.070	0.057	2.586
	Social anxiety	1, 40	0.644	0.427	0.016	1.608
	Interaction	3, 120	0.788	0.503	0.019	3.996
Search time	Facial expression	3, 120	0.2860	0.835	0.007	14.958
	Social anxiety	1, 40	0.968	0.331	0.024	1.345
	Interaction	3, 120	0.0751	0.973	0.002	16.883

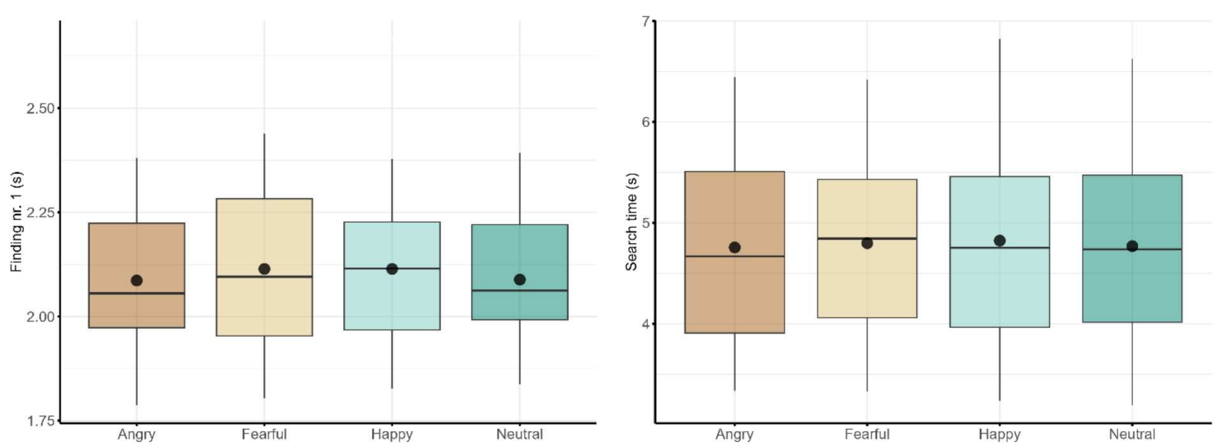

Figure 5. Reaction times for finding the first number (left panel) and for finding all the numbers (right panel). Findings are presented across distractor emotions. Black dots show the means of the variables.

Table 6. Results of the GLMMs with search performance (indicated by reaction time for finding the first number and search time) as dependent variables and arousal ratings and social anxiety as independent predictors.

		df	*F*	*p*	*β*
Finding number 1	Arousal	1, 410	4.543	0.034	−0.188
	Intensity	1, 410	1.133	0.288	0.095
	Social anxiety	1, 410	0.161	0.689	0.020
	Arousal x Intensity	1, 410	1.429	0.233	−0.058
	Arousal x Social anxiety	1, 410	1.346	0.247	−0.100
	Intensity x Social anxiety	1, 410	0.341	0.560	0.052
	Arousal x Intensity x Social anxiety	1, 410	0.637	0.425	−0.038
Search time	Arousal	1, 410	0.170	0.680	−0.036
	Intensity	1, 410	<0.01	0.999	<0.01
	Social anxiety	1, 410	10.209	0.002	0.194
	Arousal x Intensity	1, 410	0.172	0.679	−0.02
	Arousal x Social anxiety	1, 410	0.014	0.906	−0.01
	Intensity x Social anxiety	1, 410	1.430	0.232	0.105
	Arousal x Intensity x Social anxiety	1, 410	2.104	0.148	−0.068

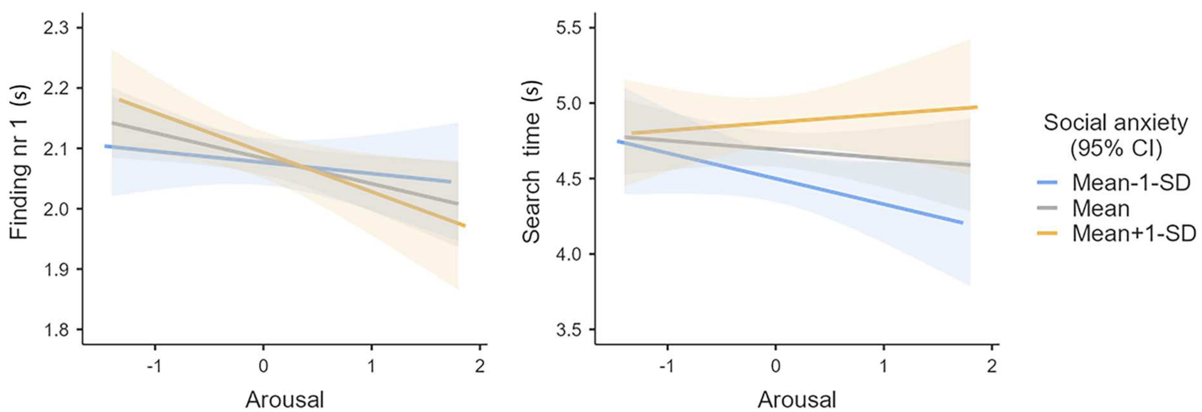

Figure 6. The left panel shows the relationship between search performance indicated by reaction time for finding the first number (in seconds) and social anxiety at various levels of arousal. The right panel shows the relationship between search performance indicated by search time (in seconds) and arousal at various levels of social anxiety.

understanding of how emotions affect visual search performance. In this aspect, our results were similar to those of Experiment 1, as we found an effect of arousal but not of emotional category. As expected, we found the opposite of the effect we observed in Experiment 1, i.e., higher levels of arousal increased performance. However, this was only evident in bottom-up attentional processing and not in executive attentional processes. This is in line with past studies investigating the effect of arousal elicited by emotional faces (Saito et al., 2021; Sawada & Sato, 2015; Sawada, Sato, Uono, et al., 2014; Svärd et al., 2014). The novelty of our finding is that it seems that emotional faces are found faster due to an advantage in involuntary attentional processing (e.g., salience) and not due to reasons that have to do with voluntary attention (e.g., task instructions). The results may also mean that the effect of arousal elicited by faces is either smaller or persists for a shorter duration compared to other types of stimuli (such as complex scenes of violence, injury, erotica, etc.) (Leclerc & Kensinger, 2008; Mather & Sutherland, 2011; Sutton & Lutz, 2019; Zsido et al., 2018, 2019, 2020). Unfortunately, we could not test the effect of valence in Experiment 2, as such ratings were not available (Goeleven et al., 2008) and the large number of individual faces presented to one participant (and the length of the experiment) precluded us from collecting ratings on the sample as we did in Experiment 1. Nevertheless, our findings lead to theoretical questions on how facial emotional stimuli can be interpreted in the framework provided by dimensional emotion theory and how they relate to other types of emotionally charged stimuli.

We replicated our findings regarding the effects of social anxiety in Experiment 1, as higher levels of social anxiety resulted in worse performance. The result of Experiment 2 also shows, which is a novel finding, that in contrast to arousal, social anxiety influences processing more on a top-down than a bottom-up level. This is in line with previous findings suggesting a link between social anxiety and cognitive dyscontrol (Shi et al., 2019). The results justify the decision we made after Experiment 1 to measure variables reflective of bottom-up and top-down processing separately. Again, we did not find interactions with arousal contradicting our initial hypothesis that the emotional effects would be more pronounced in socially anxious individuals than in nonanxious individuals. This also replicates our findings in Experiment 1.

General discussion

Faces are highlighted objects of human visual perception, as they may hold vital cues about a number of social behaviors (Behrmann & Avidan, 2022; Coelho et al., 2010; Kovács-Bálint et al., 2013). The visual perceptual system is thought to be hard-wired to detect human faces (Csibra et al., 2004; Grill-Spector et al., 2004; Grossmann et al., 2007; Leppänen et al., 2007; Stefanics et al., 2012) and to prioritize emotionally charged stimuli (such as faces with emotional expressions) over neutral stimuli in visual processing (Hedger et al., 2016; Niu et al., 2012; Pilarczyk & Kuniecki, 2014; Schupp et al., 2006). A vast number of studies have been conducted investigating these questions in the past three and a half decades, but the results are mixed to date. We identified and sought to explore two possible solutions, one that has been previously noted (i.e., the effect of arousal) and one that only a small number of studies used to test these effects in this context (i.e., using emotions as task-irrelevant stimuli). Furthermore, we also sought to explore the potential modulating effects of social anxiety, which was also often neglected in this line of research.

Throughout two experiments, we found that the level of arousal elicited by emotional faces can better describe their effects on visual search performance compared to the discrete emotional categories. This arousal presumably mostly affects involuntary attentional processes and may be less effective than arousal elicited by other types of stimuli. Moreover, the arousal conveyed by task-irrelevant emotional faces has different effects based on how the stimuli are presented. Presented as distractors throughout a task, the higher the arousal, the more distracting the face is, thus diminishing performance possibly because resources are devoted to active inhibition (Burra et al., 2017; Melloni et al., 2012; Xu et al., 2023; Zsido et al., 2022; Zsido, Stecina, et al., 2021) in addition to focusing on the primary task. However, when presented immediately before a visual search task, higher levels of arousal result in better performance, possibly because they activate the arousal system, initiating readiness for action (LeDoux, 2012; Olofsson et al., 2008; Pessoa, 2013; Zsidó et al., 2019).

Our findings also showed that social anxiety diminishes attentional performance even in nonclinical samples (Armstrong et al., 2013; Hindi Attar et al., 2010; Mogg et al., 1997). This effect could be in line with previous studies proposing a general issue in facial information processing in social anxiety due to altered neural response to faces compared to nonanxious individuals, which occurs regardless of the emotional content (Gentili et al., 2016; Machado-de-Sousa et al., 2010; Philippot & Douilliez, 2005). The fact that we did not find an interaction between facial expression information (category or arousal) and social anxiety may support this notion of a general problem. That is, the arousal effect was not more pronounced for more socially anxious participants because they have an altered response regardless of stimulus arousal. This would imply that social anxiety differs from specific phobias– as suggested by the DSM-V (American Psychiatric Association, 2013) – in that the magnitude of attentional biases is not related to the level of anxiety compared to other phobias (Abado et al., 2021; Cisler et al., 2007; Cisler & Koster, 2010; Mogg & Bradley, 2002; Schofield et al., 2013). However, it must be emphasized that these are only non-significant results and not evidence of lack of effect. Therefore, in the absence of a clinical sample in our study, we can only claim that the effects of arousal and social anxiety appear to be independent of each other in a non-clinical, healthy sample. Furthermore, our results can only be interpreted with caution as evidence of this deficit because we did not use non-face distractors (e.g., houses) as control stimuli. Therefore, we do not know whether the reduced performance at higher levels of social anxiety is related to the presence of facial stimuli. As an alternative to this explanation, it can be noted that higher nonspecific anxiety (which often correlates with social anxiety) has been reported to be associated with impaired performance on tasks requiring voluntary attentional control (Eysenck et al., 2007; Eysenck & Derakshan, 2011). However, we did not measure nonspecific anxiety in the present study, making it difficult to compare our results with this explanation.

It has been argued that attentional biases might not be as important in the conceptualization of social anxiety as past studies in the field stated (Heeren, Mogoaşe, Philippot, et al., 2015). We predominantly observed the effect of social anxiety on executive attentional processing, i.e., inhibiting task-irrelevant emotional faces to focus on the primary task was harder for more socially anxious individuals. Our results do not support the involvement of a bottom-up attentional bias that many interventions seem to target (MacLeod et al., 2002). This is also in line with past studies underscoring the importance of goal-directed behavior and showing that attentional biases are more pronounced when emotions appear as task-irrelevant distractors that need to be inhibited, especially for anxious individuals (Dodd et al., 2017; Raeder et al., 2019; Vogt et al., 2022). The method we used could provide a more reliable alternative paradigm to study attentional biases involved in social anxiety (McNally, 2018) and offer a new opportunity to modify top-down attentional biases. Interestingly, despite the difference between the experiments, we found similar effects regardless of whether the face was present during the task in the background (in Experiment 1) or the face was presented before the task but not during it (in Experiment 2). A previous study using task-irrelevant emotional faces as distractors has shown a disruptive effect in a visual search task (Raeder et al., 2019). It has been shown that negative emotional experiences such as being exposed to stimuli that are considered unpleasant for the individual can negatively affect working memory capacity (Curci et al., 2013; Schmeichel, 2007; Schmeichel & Tang, 2015). In both experiments presented here, emotional faces could have affected working memory resources by triggering cognitive emotion regulation strategies. The reason behind this could be the use of putatively maladaptive emotion regulation strategies such as suppression or rumination (Curci et al., 2013; Plass & Kalyuga, 2019). Social anxiety has been linked to a general emotion regulation deficit thought to be behind irrational automatic thoughts appearing in patients with social anxiety disorder in social settings (Hope et al., 2010). Consequently, issues with emotion regulation could be another one of multiple causal factors in the emergence of social anxiety disorder (Heeren, Mogoaşe, Philippot, et al., 2015).

It shall be noted that we only found evidence for the effect of social anxiety in the GLMM but not in the GLM in both experiments. The discrepancy in results between the GLM and GLMM analyses regarding the main effect of social anxiety can be attributed to differences in the variables included in each model. Specifically, in the GLM analysis, we used picture category as a within-subject factor and social anxiety as an independent predictor. In contrast, in the GLMM analysis, we used picture arousal ratings and social anxiety (and valence in Experiment 1, intensity in Experiment 2) as predictors, and picture category as a random effect. These differences in model specification, particularly the inclusion of arousal rating and the treatment of picture category as a random effect in the GLMM, likely account for the observed discrepancy in the main effect of social anxiety. By including the arousal rating and accounting for the random effects of picture category, the GLMM provides a different perspective on the data, which may lead to variations in the estimated effects.

Some limitations of the study should also be noted. The fact that we did not find a result of arousal on the total search time in Experiment 2 could also be explained by a habituation effect that we did not investigate in the present study. Furthermore, and somewhat in a similar vein, the cumulative effects of sustained exposure to (emotional) facial stimuli in social anxiety could be behind our results. That is, the negative correlation between performance and arousal may also be an overall effect of sustained aversive exposure leading to increased defensive activation (Smith et al., 2005). Future studies are needed to investigate effects that are developed throughout an experiment (not trial-by-trial), possibly using physiological measures such as skin conductance or EKG. In addition, a check during the review process revealed that the variance (0.56 vs. 0.75) and range (3.17 vs. 4) of arousal ratings were lower in Experiment 2 than in Experiment 1, which may also account for the lack of arousal effect in Experiment

2. Moreover, while we had arousal ratings in both experiments, we could only explore the effect of valence in Experiment 1. Although we did not find significant results with valence, future studies are needed to determine whether this is a true negative finding. Again, we need to underscore that non-significant results cannot be considered as evidence of lack of effect. Furthermore, in Experiment 1, we were not able to reliably test the influence of distractors when they are in direct competition with the target in the initial visual search process and before inhibition or habituation to the emotional background stimulus can take place. Although we used touchscreen monitors to collect data, we did so only to validate the counting score and not to collect RTs. Although we analyzed RTs, these results must be interpreted with caution because the database was noisy and contained a large amount of missing data. Finally, we did not measure individual differences beyond social anxiety. While taking into account the possible effect of social anxiety is a strength and novelty of our study, our results have shown that other factors, such as cognitive emotion regulation, are also crucial to fully understanding the underlying mechanisms.

In sum, we found no effect of valence, but we found further evidence considering the effect of arousal. Our interpretation of the results is that emotional faces are possibly found faster due to an advantage in involuntary attentional processing (e.g., salience) and not due to reasons that have to do with voluntary attention (e.g., task instructions). Furthermore, we have demonstrated that higher levels of social anxiety result in worse visual search performance if faces are used as task-irrelevant stimuli regardless of the level of arousal, emotional category, and presentation method. The effects seem robust, with two separate experiments on independent samples arriving at the same conclusion. Our results could have practical relevance to the field of visual research and the treatment of social anxiety, while they also raise new questions for future studies.

Notes

1. This is a deviation from the analysis plan. Based on the well-reasoned critique of one of the reviewers, we repeated the GLM and GLMM analysis with RTs for finding number 1 as the dependent variable. We only used a touchscreen monitor to record responses during the experiment to validate the last number found and not with the purpose of using RTs. Therefore, originally it was not included in the analysis plan. Since the RT data were noisy and contained missing data and thus these results must be interpreted with caution, we decided not to include the analysis in the main text. However, for transparency reasons they are presented in full in Supplementary Material 2. Central tendencies are presented in Supplementary Material 1.
2. This is also a slight deviation from the original statistical analysis plan as we only sought to look for significant results and not providing evidence for the H0. However, one of the reviewers, quite rightly, noted that we made some claims in the Discussion that can only be sustained if we do present evidence for H0.

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Data availability statement

Data sets that include computed study variables are available on the Open Science Framework: https://osf.io/cwz8n/.

Author contributions

ANZS: Conceptualization, methodology, software, supervision, project administration, funding acquisition, writing – original draft, reviewing and editing; BLK: Data curation, visualization, formal analysis, writing – reviewing and editing; JB: Data curation, visualization, formal analysis, writing – reviewing and editing; LB: Conceptualization, methodology, supervision, writing – original draft, reviewing and editing.

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