The effect of cognitive load in emotional attention and trait anxiety: An eye-movement study.

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Abstract

There is extensive debate on the automaticity of attentional processing of emotional information. One core feature of automaticity is the independence of processing emotion from factors that can affect attention such as cognitive load. In the present study we investigated whether processing of emotional facial expressions was dependent on cognitive load using a visual search paradigm. Manual responses as well as eye-movements were recorded. While both measures showed that emotional information captured attention more strongly than neutral information, manual responses indicated that load slowed reaction times only for "pop-out" emotion conditions; no increase was seen for all-emotional displays. While this suggests that the saliency of emotion was reduced, eye movement data showed that effects were caused by improvements for all-emotional displays in target processing efficiency. Additionally, trait anxiety did not influence threat processing, but costs were observed under load that were not present for non-anxious subjects. Our results suggest that while load can interfere with task performance, it may not affect emotion processing. Our findings highlight the importance of eye movement measures in accounting for differences in manual response data and provide novel support to theories of anxiety.

Keywords: Attention, emotion, eye-movement, visual search, anxiety

Introduction

It has been argued that the cognitive processing of emotional, and especially threat-related, information has a special status in animals and humans (Oatley & Johnson-Laird, 1987); an important characteristic being its reflexive orienting of attention to threat and the prioritization of threat over other stimuli and task-demands. Evolutionary accounts of threat processing dictate that such prioritization can be considered adaptive, hard-wired, and present in all individuals (Lang, Bradley, & Cuthbert, 1997; Mathews & Mackintosh, 1998; Mogg & Bradley, 1998; see Öhman et al., in press this issue). There is also emerging evidence from electrophysiological recordings to indicate that early visual components are influenced by the emotional significance of stimuli (e.g., Stolarova, Keil, & Moratti, 2006). Indeed threat-related stimuli have been shown to activate amygdala response even when presented subliminally (Morris, Öhman, & Dolan, 1996).

If emotional material is processed pre-attentively, and can have potent effects on the orienting of attention, attention itself will not influence initial emotion processing. However, recent challenges (see e.g. Pessoa, 2005) have led to considerable debate about how threat is processed and whether it depends on attentional resources. For example, Stein, Peelen, Funk and Seidl (2010) saw that the advantage for conscious detection of threat images in the attentional blink paradigm, compared to positive images, was abolished when attention was consumed by another visual task. Pessoa, Kastner and Ungerleider (2002) also found that amygdala response to emotion was hampered when attentional resources were taxed, and similar findings were reported by Bishop, Jenkins and Lawrence (2007). But there is also evidence that emotion can activate the amygdala irrespective of the focus of attention (see Vuilleimer, Armony, Driver & Dolan, 2001), and indeed this position is seen as the more traditional belief on the basis of influential theories of automaticity such as by LeDoux (1995).

An important distinction must be made between how emotion may be impacted upon by early attention, and how it may interact with later cognitive facets and working memory. Models of selective attention such as Load Theory (e.g. Lavie, 2005) propose that visual demands on attention reduce early resources available to process additional information, extended to include emotional content by others (Pessoa et al, 2002; Bishop, Jenkins & Lawrence, 2007). Whether or not demands on early attention (i.e. perceptual load) can modulate emotion processing, far less emphasis has been paid on what happens when perceptual demands on attention are low. Under this circumstance, it is presumed that emotion will be processed automatically, regardless of one's view about the importance of early attention. Thus, information processing depends upon later cognitive influences such as central executive control.

Working memory is believed to be a major process in keeping one's goals in mind, and for co-ordinating between tasks (Shallice & Burgess, 1996). For example, in visual search, working memory is believed to be used to maintain target information (Duncan & Humphreys, 1989). Therefore, loading working memory should disrupt one's ability to maintain task goals and lead to increased likelihood of distraction by irrelevant information. Consistent with this, cognitive load has been shown to disrupt performance in the antisaccade task (Roberts, Hager & Heron, 1994), increase the likelihood of attentional capture (Lavie & De Fockert, 2005), and result in greater interference by response-competing distracters (De Fockert, Rees, Frith & Lavie, 2001). Individuals lower in working memory capacity have also shown evidence of generally greater distraction outside of load manipulations (see Kane & Engle, 2002).

With this in mind, working memory may also interact with emotion. Previous work has focused on how cognitive load can affect response to negative emotion in a more thought-driven manner. For instance, whilst conducting working memory tasks like digit rehearsal or math problems, feelings towards concurrently presented negative images are reduced in intensity (Van Dillen, Heslenfeld & Koole, 2007), and amygdala activity to negative emotion can be reduced either by reappraisal and down-regulating negative feelings, or equally by distracting oneself with another task (McRae, Hughes, Chopra, Gabrieli, Gross & Ochsner, 2010). However, such previous work examines how loading working memory can affect emotional responses in the sense of thinking about negative emotion; when verbal processes are engaged, it is known that additional thought generation or mind wandering is reduced (Teasdale et al, 1995). Thus, evidence that negative emotions are attenuated through occupying working memory are interesting, but clearly cannot be applied to the idea that the ability of threatening information to capture and orient attention is affected by working memory.

That said, recent studies have proposed that simple threat processing in attention tasks can be hampered under cognitive load, though studies investigating this topic are few in number. Van Dillen and Koole (2009) induced a cognitive load, either through concurrent mathematics or digit rehearsal of one or eight digits, while participants responded to the gender identity of angry or happy faces. The authors found that angry faces took longer to respond to than happy ones, presumably through the angry faces capturing and holding attention, reducing processing efficiency in responding. Under high load, however, the difference between angry and happy trial reaction times was abolished. The authors argued that cognitive load may promote the processing of task-relevant information and reduce the disruptive effect of threat. We note, however, that this interpretation is somewhat at odds with previous work suggesting that a cognitive load should increase distraction, and also that in their experiments reaction times increased under load more for happy than angry trials. Therefore, it is difficult to interpret the finding that load increased reaction times to negative emotion to a lesser extent than it did for reaction times to positive emotion as evidence that load hampered threat processing. Another study by Pecchinenda and Heil (2007) found little impact of cognitive load on emotion. In their task (Experiment 3) participants responded to the valence of a target word, either positive or negative, superimposed over angry, happy or neutral faces. The authors primarily looked for increases in response-competition under load, having replicated the effects on wholly neutral stimuli seen by De Fockert et al (2001). However, the authors failed to replicate the load effect in this experiment, finding a compatibility effect under both load conditions yet no increase, suggesting that emotional distraction may be processed independently from working memory manipulations. Whether or not load affected reaction times differently for each particular expression was not assessed, as the authors' focus was on compatibility effects when collapsing across distractor expression. Moreover, whether cognitive load could increase distraction within the same experiment for non-emotional material could not be gleamed.

In appreciating these findings, the possible role of working memory in emotion processing has thus far found little empirical support. As with non-emotional items, a cognitive load may enhance threat processing by reducing one's ability to regulate and override threat's effect in pulling our attention. Equally, attending to emotion may be disrupted if cognitive resources are taxed and attentional reactions to threat require working memory to initiate. Finally, threat may grab attention in an automatic manner, overriding task goals and orienting attention outside of cognitive control. In the present study, we sought to investigate the value of these accounts in a visual search task modulating levels of cognitive load.

Two points set our study apart from previous investigations. Firstly, we aimed to assess levels of trait anxiety and how load may affect individuals high or low in such a trait differently. Trait anxiety has been associated with a preferential bias in attention towards threatening information (see Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg & van IJzendoorn, 2007, for a review). Interestingly, Bar-Haim et al (2007) found that, when anxiety is measured, there seems to be a consistent lack of a threat bias for individuals with low levels of anxiety. This point is intriguing considering that threat processing is often seen as hard-wired and automatic. It may be that low anxious individuals process threat but simply control their attention through working memory and prevent orienting of attention towards such items to occur, or that responses are simply attenuated when arousal caused by the threat is diminished. While a load on early attention has been shown to attenuate threat processing in the amygdala even for high anxious subjects (Bishop et al, 2007), how cognitive load may affect threat processing is an unanswered question when taking into account anxiety. Secondly, in addition to behavioural responses, we also measured eye movements. While comparing manual response times are a good measure of distractibility, some authors have argued that the presence of threat can speed up behavioural response (Flykt, 2006), while others have suggested that threat might disrupt responding (Mogg, Holmes, Garner & Bradley, 2008). Additionally, Derakshan and Koster (2010) demonstrated that eye tracking can reveal saccades to distractor items before the target is fixated, and after target fixation prior to the manual response being given. Thus, recording eye movements can give additional insights into attentional biases that may be masked by simply behavioural reaction time data.

The current investigation

The present study was designed to examine attentive processing of threat under cognitive load, taking previous limitations into account. To reduce ambiguity over the dependent measure of attentive processing of threat, we used manual reaction times as well as eye-movements as dependent variables in a visual search paradigm. In this task, participants can be provided with different type of instructions. In the present study we used the “odd-one-out” instructions where individuals were instructed to see whether a display of 8 faces contained a face (target) with a different emotional expression. By manipulating the emotional expression of the target and the crowd, one can investigate speeded threat detection as well as impaired disengagement from threat through the examination of response latencies in high versus low anxious individuals. For example, an angry face (target) can be presented in a display of neutral faces (crowd) to investigate speeded threat detection. Conversely, a neutral face (target) can be presented among an angry crowd to examine attentional disengagement. In previous research, the visual search task has shown to be a sensitive paradigm to capture effects of emotional attention and modulation of anxiety-related individual differences (e.g., Byrne & Eysenck, 1995; Öhman et al., 2001; Rinck et al., 2005).

The following hypotheses were tested in this study. Firstly, if attentive processing is an automatic process mainly related to bottom-up characteristics, emotional attention will be observed under conditions of cognitive load in similar magnitude. Contrarily, if working memory is involved in facilitated detection of threat, emotional attention will be reduced by cognitive load as suggested by previous work on thought regulation and response-competition. We examined facilitated detection of threat (on trials with threatening targets) and disengagement from threat (on trials with threatening distracters) under load. Considering cognitive load has been shown to increase interference from distracting information, and working memory is involved in modulating attention, this could theoretically also result in reduced ability to disengage from threat while facilitation itself is unhindered. Finally, we tested whether individual differences in trait anxiety influence the attentive processing of threat under cognitive load.

Method

Participants

A sample of 63 participants [1] (39 female) was recruited via advertisements posted around the University of London colleges. Participants had a mean age of 28.71 (SD = 5.89). All had normal to corrected-to-normal vision and were asked to wear their glasses or contact lenses if necessary. Participants were paid £5 for participating in the experiment.

Stimuli

8 angry, 8 happy, and 8 neutral facial expressions of emotion (half male and half female) were selected from three sources of databases of facial expressions, including the Ekman and Friesen database (Ekman & Friesen, 1978), the NimStim database (Tottenham et al., 2008) and the Karolinska Directed Emotional faces set (Lundqvist & Ohman 1998). The faces were presented in greyscale and positioned against a black background. The visual angle subtended by each face, when fixated, was 2˚ 29´ x 4˚ 29´. Basic image-statistics were computed and found to be similar for all three expressions. The standard deviation of the individual mean luminances, as a fraction of the overall mean, was computed. This 'coefficient of variation' was approximately 1%.

Visual search task

Eight faces, arranged in a circle, were simultaneously shown on each trial. All faces were in the same frontal (and upright) orientation. The faces were shown in the eight 'compass-points'. The eccentricity of each face, when fixating the central cross (i.e. the radius of the circle) was 8˚ 15´.

For each of the three possible target expressions, there were two alternative non-target (crowd) expressions. This produced six distinct target/crowd pairings, which were: Angry target/Happy crowd, Angry target/Neutral crowd, Happy target/Angry crowd, Happy target/Neutral crowd, Neutral target/Angry crowd, and Neutral target/Happy crowd. Each target expression appeared on any of the eight faces in the circle, equally often. Hence there were 48 distinct target/crowd screens. The design also incorporated catch trials, on which eight identical faces (i.e., angry, happy, or neutral) were presented.

The presentation of all trials was randomised for every participant. Participants completed 6 blocks (3 under cognitive load and 3 under no load) of 60 trials (48 target/crowd trials and 12 catch trials). A trial began with a fixation cross (width and height of 33 pixels) that appeared in the centre of the screen for 1250ms. This was followed by the stimulus-screen until a response was made or, in case of no response, for 5000ms.

Eye-tracking device and controlling software

The LC Technologies 'Eyegaze' system was used to track eye-movements (LC Technologies, 2003). This system uses the Pupil-Centre Corneal Reflection method (PCCR; Mason, 1969; Merchant & Morrisette, 1973). The eyes are lit by an infra-red source and the resulting image of (one of) the eyes is monitored. The gaze-point (intersection of the optic axis with the screen) is estimated from the image of the pupil, in conjunction with the corneal reflection of the light-source.

The screen position of the gaze-point is estimated at 60Hz, with a typical root mean square error of less than 0.6˚ (38´). The Eyegaze system estimates participants' fixations by spatial averaging over groups of gaze-points. A minimum duration of an individual fixation is defined as 100ms and the maximum fixation radius is defined as 0.6˚ (38´).

The stimuli were presented in 24-bit colour on a 1024 x 768 LCD (ViewSonic 700b, cell response-time 35ms). The presentation of the stimuli was controlled by the DMDX program (Forster & Forster, 2003), which ensures millisecond timing accuracy. Responses were recorded from a button-box (PIO-12 interface), monitored at 1000Hz by

DMDX. The Eye-tracking system was automatically synchronised to DMDX at the beginning of each trial. The Eye-gaze system is tolerant of small head movements (up to 32mm in any direction) and able to resume tracking after larger movements.

Procedure

The experiment took place in a dimly lit room that housed the eye-tracker in the Laboratory of Affective and Cognitive Neuroscience at Birkbeck University of London. Upon arrival at the laboratory participants completed a measure of trait anxiety (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983). They were seated at a distance of 60 cm from the eye-tracking device. Participants were instructed to press the corresponding button as quickly as possible whenever a face in the circle depicted a different expression. They were asked not to respond if all the faces showed the same expression. Cognitive load was manipulated in a within-subject design: On half of the blocks a two digit number appeared at the beginning of the trial. Participants were asked to count backwards in threes, out loudly, from that number, until the end of that trial [2]. The remaining three blocks did not involve any manipulation of load. Orders of blocks were counterbalanced across participants. Speed and accuracy of response, as well as the need to attend to the fixation cross whenever it appeared on the screen throughout the experiment were emphasised.

Instructions were followed by practice trials for both load and no load conditions with the visual search task depicting different faces to those that appeared in the main experimental task. The eye-tracking calibration procedure was then run, requiring the participant to fixate a series of twelve points on the screen. The main experimental task began as soon as the calibration procedure was completed. Participants were thanked and debriefed at the end of the session.

Results

Participants had a mean trait anxiety score of 39.7 (SD = 11.10; min = 20, max = 77). To test the effects of anxiety participants were divided into low (N = 29) and high-trait anxious (N = 32) groups based on a median split on the trait anxiety score: those scoring 37 and below were classified as low-anxious, and those scoring above 37 were classified as high-anxious. Mean trait anxiety for the low-anxious group was 30.86 (SD = 4.23) and for the high-anxious group it was 47.72 (SD = 9.09). The two groups differed significantly on trait anxiety levels, $t(59) = 9.42$, $p<.001$.

Manual responses (reaction times)

Reaction times were recorded from the onset of the face array. Less than 3% of the data was lost due to outliers (reaction times less, or greater, than 3SD of each participant mean). Figure 1 shows mean reaction times for target detection in each of the six conditions as a function of cognitive load.

Insert Figure 1 here

A 6 x 2 x 2 Mixed ANOVA with Condition and Load as within-subjects factor and Anxiety group as between-subject factor revealed main effects of Condition, $F(5,295) = 130.35$, $p<.001$, $\eta^2 = .69$, with participants being slowest to detect an angry target in a happy crowd and a happy target in an angry crowd which seemed to be unaffected by Load. There was a main effect of Load, $F(1,59) = 6.55$, $p<.02$, $\eta^2 = .10$, with longer reaction times under load (M = 1803, SD = 386) than no load (M = 1721, SD = 327). There was also a Condition X Load interaction, $F(5, 295) = 3.12$, $p<.02$, $\eta^2 = .05$.

Corroborating this interaction, we tested if (a) facilitated detection of threat is influenced by cognitive load, and (b) if cognitive load interferes with disengagement from threat processing. Analysis showed that load interfered with facilitated detection of angry, $t(60) = 2.75$, $p<.01$, as well as happy targets, $t(60) = 3.05$, $p<.004$, when in neutral crowd. Accordingly, participants were slower to detect emotional targets under load (angry: M = 1552, SD = 468; happy: M = 1522, SD = 440) compared with no load (angry: M = 1423, SD = 384; happy: M = 1417, SD = 352). Analysis also showed that load interfered with both the disengagement from threat on trials with a neutral target and an angry crowd (no load: M = 1675, SD = 372; load: M = 1788, SD = 439), $t(60) = 2.85$, $p < .007$, but equally to find a neutral target amongst a happy crowd (no load: M = 1769, SD = 410; load: M = 1864, SD = 388), $t(60) = 2.39$, $p = .02$. Finally, load had no significant effect on finding an angry target in a happy crowd, $t(60) = 1.22$, $p > .2$, or vice versa, $t < 1$.

Analysis showed a main effect of Anxiety, $F(1,59) = 5.17$, $p < .03$, $\eta^2 = .08$, as well as a significant Load X Anxiety interaction, $F(1,59) = 5.87$, $p < .02$, $\eta^2 = .09$. While low and high anxious individuals did not differ in their reaction times under the no load condition, $t(59) = 1.38$, $p > .1$, high anxious individuals showed significantly longer reaction times under load, $t(59) = 2.81$, $p < .01$. Moreover, low anxious individuals showed no actual increase in reaction times generally under load (no load: M = 1661, SD

= 297; load: M = 1665, SD = 316), t(28) = .138, $p = .89$), whilst high anxious individuals showed increased costs (no load: M = 1776, SD = 347; load: M = 1929, SD = 405), t(31) = 2.97, $p < .007$). The three-way interaction of Load X Condition X Anxiety was not significant, $F(5,295) = 1.69$, $p = .16$.

Eye-movement data

Table 1 shows the descriptive statistics for the following indices as a function of Condition and Load. For the eye-movement data we presented several indices related to initial target detection, attentional disengagement target processing efficiency and fixations made after the target was located. Although other indices can also be examined (e.g., Derakshan & Koster, 2010), for reasons of parsimony, we selected the indices that most directly related to our hypotheses.

Insert Table 1 here

Time taken to fixate target

This was defined as the time participants spent on crowd faces prior to fixating the target, i.e., the elapsed time between onset of visual display and fixating target. A 6 (Condition) x 2 (Load) x 2 (Anxiety Group) Mixed ANOVA revealed a main effect of Condition, $F(5,295) = 120.56$, $p < .001$, $\eta^2 = .67$, which was qualified by a quadratic trend to indicate that participants took longer to fixate target when target and crowd were both emotional, followed by conditions where crowd was emotional and target neutral, and emotional targets in neutral crowds, $F(1,59) = 37.42$, $p<.001$. There was a main effect of Load, $F(1,59) = 28.05$, $p < .001$, $\eta^2 = .32$, with participants taking longer to fixate a target under load (M = 1173, SD = 225) than under no load (M = 1050, SD = 150). Load did not interact with Condition, $F < 1$. A two-way interaction of Anxiety X Load was observed, $F(1,59) = 12.44$, $p = .001$, $\eta^2 = .17$. This showed that Load affected the time taken to fixate target for the high-anxious group (no load: M = 1043, SD = 150; load: M = 1241, SD = 247), $t(31) = 5.09$, $p < .001$, more than it did in the low-anxious group (no load: M = 1059, SD = 153; load: M = 1098, SD = 174), $t(28) = 2.05$, $p = .05$. No other main effects or interactions were significant.

Mean crowd dwell time

This was defined as the mean time participants spent on each individual face in the crowd before fixating target. This index defined the attention grabbing power of each crowd face, i.e., attentional dwell time. A 6 (Condition) x 2 (Load) x 2 (Anxiety group) Mixed ANOVA on this data revealed a main effect of Condition, $F(5,295) = 33.43$, $p<.001$, $\eta^2 = .36$, qualified with a significant cubic trend, $F(1, 59) = 5.09$, $p<.03$, to indicate that angry crowd faces grabbed more attention than happy crowd faces followed by neutral crowd faces (M = 208 vs. M = 201 vs. M = 187, respectively) . There was a Load X Anxiety interaction, $F(1,59) = 6.10$, $p<.02$, $\eta^2 = .09$. High-anxious individuals showed a tendency to spend longer fixating each face under load (M = 205, SD = 38), compared with no load (M = 198, SD = 24) but this difference was not significant, $t(31) = 1.68$, $p = .10$. On the other hand, low-anxious individuals spent less time fixating each face under load (M = 195, SD = 25) compared with no load (M = 200, SD = 23), $t(28) = 2.08$, $p < .05$. No other effects reached significance.

Target processing efficiency

This was defined as the elapsed time between landing fixation on target and behavioural reaction time as assessed by button press, and was used to assess the time taken to process the target. A 6 (Condition) x 2 (Load) x 2 (Anxiety Group) Mixed ANOVA revealed a significant main effect of Condition, $F(5,295) = 33.67$, $p < .001$, $\eta^2 = .36$, with slowest target processing times for when both target and crowd were emotional and fastest target processing times for when an emotional target was embedded in a neutral crowd. There was no main effect of Load, $F(1,59) = 2.49$, $p = .12$, but a Load X Condition interaction, $F(5,295) = 2.83$, $p<.03$, $\eta^2 = .05$. This interaction showed that load enhanced processing efficiency of an angry target in a happy crowd (no load: M = 780, SD = 283; load: M = 708, SD = 261), $t(60) = 2.44$, $p < .02$, as well as enhanced processing of a happy target in an angry crowd (no load: M = 850, SD = 283; load: M = 777, SD = 314), $t(60) = 2.29$, $p < .03$. This pattern of findings is depicted in Figure 2. There was also a main effect of anxiety, $F(1,59) = 6.89$, $p = .011$, $\eta^2 = .11$, with high anxious individuals generally slower in target processing (M = 1142, SD = 172) when compared to low anxious individuals (M = 1079, SD = 155). Anxiety did not interact with load or condition.

Insert Figure 2 here

Number of crowd fixations after fixating target

This was defined as the number of fixations participants made on crowd faces after fixating target, complimenting target processing time by showing how much of time spent between target detection and pressing a manual response was taken up by processing/fixating distractor crowd faces (see Table 1). A 6 (Condition) x 2 (Load) x 2 (Anxiety Group) Mixed ANOVA revealed a main effect of load, $F(1,59) = 11.27$, $p = .001$, $\eta^2 = .16$, with fewer fixations made on distractor crowd faces following fixation on target under load (no load: M = 1.25, SD = .58; load: M = 1.07, SD = .56). There was also a main effect of condition, $F(5,295) = 29.35$, $p < .001$, $\eta^2 = .33$, with a cubic trend showing more post-target fixations made on displays with angry targets and happy crowds and vice versa compared to all other conditions, $F(1,59) = 11.49$, $p = .001$, $\eta^2 = .16$. A load X condition interaction was also seen, $F(5,295) = 6.41$, $p < .001$, $\eta^2 = .10$, qualified by a significant cubic trend ($F(1,59) = 4.14$, $p < .05$) indicating fewer post-target fixations on crowd items in all-emotional displays under load, followed by neutral target in emotional displays and finally emotional target in neutral displays.

Lastly, there was a main effect of anxiety, $F(1,59) = 5.91$, $p = .02$, $\eta^2 = .09$, whereby high anxious participants made more crowd fixations following landing on target compared to low anxious participants (low anxious: M = .99, SD = .36; high anxious: M = 1.31, SD = .61). Once more, anxiety did not interact with load or condition.

Discussion

The current study examined whether threat processing is affected by cognitive load. In theoretical models of threat processing there is extensive discussion on the degree to which threat processing is influenced by bottom-up characteristics, such as stimulus saliency, versus top-down mechanisms such as goal-directed behavior and working memory processes in identifying task-relevant and task-irrelevant information (Cisler & Koster, 2010; Eysenck et al, 2007; Mathews et al, 1997). Examining whether threat processing is affected by cognitive load provides a partial answer to the question of whether threat processing occurs in an automatic fashion, independent from the availability of cognitive resources or alternatively is influenced by shared resources with other aspects of working memory (Pessoa et al, 2002), or can be suppressed by cognitive control. In order to obtain a fine-grained picture of the influence of cognitive load on various components of attentive processing of threat we combined a visual search paradigm with eye-registration methodology. The results of this study indicate that emotional information captures and holds attention more strongly than neutral information, that cognitive load appeared to hamper emotion processing, and that anxiety was associated with greater costs to performance under load. These findings are discussed below.

Emotion captures and holds attention

In the current study manual response time as well as eye-movement data indicate that emotional information captured attention. That is, emotional targets in neutral crowds were responded to faster than neutral targets in emotional crowds. Moreover, initial target fixation to emotional targets was faster than to neutral targets, and attentional dwell time was longer for emotional crowds compared with neutral crowds. Interestingly, in our data there was little evidence for a threat superiority effect, which has been observed in several previous studies (e.g., Fox et al, 2000). In this regard, it is worth mentioning that several studies now indicate that valence per se is not the most important determining factor for attentional capture but that the arousal value of stimuli is associated with attentional capture (Schimmack, 2005; Vogt, De Houwer, Crombez, Koster, & Van Damme, 2008), which also argues against the notion of threat-superiority.

Emotion processing under load

With regard to our specific predictions of threat processing under load, we found that threat processing was hampered under cognitive load at the level of manual responses and, through eye-tracking data, that this effect was driven by an increased time to fixate the target, but crucially not due to more fixations made on distracters. Thus, our findings suggest that diverting cognitive resources between the visual search and counting tasks caused a general slow-down in responses.

Interestingly, examining manual responses, load appeared to slow reaction times in all conditions except when a happy face was presented in an angry crowd or vice versa. Superficially, this would suggest that load may have disrupted the emotional saliency of information; an angry/happy face in a neutral crowd would take longer to find if the saliency of the emotional target was reduced, and equally a neutral target in an emotional crowd would stand-out less if target to non-target similarity is increased (Duncan & Humphreys, 1989). For trials already requiring serial search, however, such as all-emotional displays, if load hampered emotional saliency then reaction times would be less affected as the target cannot “pop-out” as easily to begin with.

However, with the aid of eye-movement measurement, we were able to pinpoint this discrepancy precisely; load appeared to improve target processing efficiency time for all-emotional displays, explaining why reaction times suffered in all other conditions but not these, and why there was no interaction of load and condition in time taken to fixate target. Thus, while the cost of load seemed to affect conditions differently, as indicated by increased response times, our eye-movement data shows that we cannot solely rely on manual response times to determine emotion-specific attentive processing. Rather, under increased cognitive demands, all displays were simply more difficult to efficiently complete regardless of emotional valence (in the sense of time to fixate target), demonstrating that target items involving emotion are not immune to cognitive interference caused by cognitive load and yet are not differentially affected.

Why target processing efficiency for all-emotional displays was enhanced under load is unclear, but when measuring fixations made to other crowd items following landing fixation on target, we saw that load not only reduced this interference to processing efficiency but reduced it most for all-emotional displays. Thus, once participants had fixated a discrepant emotional target in an emotional crowd, they were faster to respond and made fewer follow-up eye movements under load than in other conditions.

Interactions of emotion and cognition

While the differences in condition response times under load were pinpointed by differences in target processing efficiency, performing a concurrent task did not increase or decrease the saliency of emotional relative to neutral targets. However, a general cost in time to fixate target was observed under load regardless of valence. In this sense, our data suggests that cognitive load does have an effect on emotion processing, but only in affecting the cognitive factors involved in visual search and orienting attention such as the role of working memory in keeping the target template in mind during such tasks (Duncan & Humphreys, 1989).

With regard to whether cognitive resources are required in processing emotion, our manual response data supported this assumption by suggesting that emotion lost its salient qualities under load, though this finding was negated by the vital inclusion of eye movement recording. Thus, we cannot conclude that emotion processing does require cognitive resources and, as outlined in our Introduction, there is inconclusive evidence to suggest that it does. It remains possible that our load manipulation, counting back in multiples of three, was not a strong enough demand and that a more potent load may have caused differences seen in emotion processing. What is clear, however, is that load can have differential effects on conditions in target processing efficiency in visual search tasks. As a consequence, future work may benefit from utilizing eye-tracking as a measure, as our data provides a cautionary note in interpreting purely behavioural responses that showed an interaction of load and condition that was not seen in eye movement latencies to fixate targets.

Anxiety under cognitive load

Finally, our findings with regard to the influence of trait anxiety require some consideration. In previous work, individual differences in anxiety levels were often neglected, which is problematic as the automaticity of threat processing may vary between high and low anxious individuals (see Fox et al, 2005; Bar-Haim et al, 2007). If threat processing is more automatic in high anxious individuals, this would be less affected by cognitive load in high compared with low anxious individuals. In the current study we tested a relatively large sample and used a median-split procedure to explore influences of anxiety on threat processing. Overall we failed to find that high anxious individuals' threat processing was less affected by cognitive load compared with low anxious individuals, and indeed no marked difference even under the no load condition.

However, we found that anxious subjects were generally slower in reaction times in the visual search task. Eye movement data showed that high anxious subjects also demonstrated reduced target processing efficiency between fixating target and responding, which was likely driven by further fixations on distractors once the target had been fixated. This may suggest that anxious subjects were more likely to doubt their choice on finding the target, and so increased the likelihood of checking nearby distractor faces prior to manual response. Crucially, we also noted a number of interesting interactions with anxiety under load for both manual responses and eye movements. When a load was imposed, high anxious subjects experienced slower response times whereas low anxious individuals showed no evidence of a cost. Eye movement data demonstrated that this effect was caused by longer latencies before landing fixation on target, possibly explained by increased fixations on crowd items under load that just missed significance, whereas the low anxious made significantly fewer crowd fixations under load.

Taken together, our findings support theories of trait anxiety such as Attentional Control Theory (ACT; Eysenck et al, 2007), which posits that anxiety is associated with reduced cognitive efficiency. Moreover, our findings of increased detriments to performance under load also support ACT's prediction that anxious individuals can attempt to compensate for reduced cognitive efficiency by utilizing cognitive effort to placate this. With the imposition of cognitive load, compensatory strategies may have been disrupted as resources were diluted across two concurrent tasks, explaining why anxious participants showed costs under load whereas non-anxious participants did not. Thus, manipulations of cognitive load may be a useful tool in elucidating attentional control deficits in anxiety that may sometimes be camouflaged under less demanding conditions by compensatory cognitive strategies (see Ansari & Derakshan, 2011b).

Conclusions

The findings of the current investigation contribute to the literature in several important ways. First, in a visual search paradigm that is suitable to find attentional capture and holding effects of threat, we observed that emotional information in general demands attention. There was no evidence for threat specificity at any of the attentional indices, although processing of angry and happy faces did differ strongly at the level of target processing. These findings argue against a threat superiority effect which is in line with several recent studies that have observed little evidence for strong automatic threat processing (Calvo, Gutiérrez, & Fernández-Martín, this issue; Huijding, Mayer, Koster, & Muris, 2011). Moreover, the results of the present study are of importance to the debate on the automaticity of threat processing; that is, strong claims have been put forward about the automaticity of threat processing. Our data provide important evidence that threat processing can be affected by cognitive load at the level of attentive processing in terms of a slowdown, but that emotion advantages in prioritizing attention are generally maintained across conditions. Furthermore, our data indicate that threat processing is also perhaps not more automatic in anxious individuals. Lastly, our data point to a cost in task performance and reaction time in anxiety that is further revealed by cognitive load.

Clearly several limitations require consideration here. First, although stimulus material was carefully selected, one could argue that visual search was mainly performed through analysis of visual features of discrepant faces rather than the emotional expression of the faces, with a feature–based search not being divergent in high versus low anxious individuals. Yet, this account cannot explain the specific divergent pattern of eye-movements with and without cognitive load and the findings at the level of the target processing index. The latter findings suggest some degree of emotion processing during visual search instead of a purely feature-based search. Secondly, we presented the analyses based on median-split to ensure appropriate statistical power. It is important that we recognize some of the problems noted with regard to median-split analysis, however similar effects were obtained when using more extreme scores on anxiety (tertiary split).

In sum, the current study shows that cognitive load can hamper effective visual search, including when that search involves emotion, arguing against strong claims of automaticity in emotional items capturing attention immediately and unaffected by current cognitive demands. However, emotion processing itself was relatively unaffected under load, with manual response differences explained through the use of eye movement data, and suggesting that process of emotion capturing attention may not be dependent upon cognitive resources, but simply slowed down. With the benefits of eye movement data, we were able to localize the effects of load on both differences in emotion conditions and in trait anxiety performance, finding specific effects on target search time under load, and more general effects on target processing efficiency. Utilizing similar methodologies, future work may produce a more fine-grained analysis of how attentional processes are influenced by variables such as emotion, cognitive load, and anxiety.

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Footnote

1 The data for two participants were discarded due to poor calibration.

2 Participants' performance while counting was monitored by the experimenter who sat outside the testing cubicle, and prompted the participant if counting incorrectly. All participants performed the counting task at ceiling level.

Table 1. Patterns of eye-movements prior to, and after, fixating target as a function of valence of target and crowd, and load (NL = no load, L = Load)

		Condition (Target in Crowd)					
Eye-movement index		Angry in Happy	Angry in Neutral	Happy in Angry	Happy in Neutral	Neutral in Angry	Neutral in Happy
		M (SD)	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
Time taken to fixate target (in ms)	NL	1194 (195.74)	836 (193.97)	1292 (203.00)	843 (185.87)	1058 (194.36)	1081 (216.06)
	L	1304 (248.03)	948 (295.52)	1384 (306.03)	977 (266.86)	1201 (268.59)	1226 (250.90)
Crowd attentional dwell time (in ms)	NL	203 (27.30)	185 (23.99)	212 (25.72)	188 (28.26)	208 (29.56)	198 (29.36)
	L	205 (34.55)	188 (42.63)	210 (34.45)	191 (37.32)	205 (36.21)	205 (37.70)
Number of crowd fixations made after landing target	NL	1.58 (.83)	0.95 (.61)	1.68 (.83)	1.00 (.63)	1.04 (.59)	1.23 (.72)
	L	1.16 (.70)	1.03 (.61)	1.36 (.89)	0.93 (.58)	0.88 (.51)	1.04 (.72)

Figure captions

Figure 1. Mean reaction times to target as a function of target and crowd emotional expression in low- and high-anxious groups (bars indicate standard errors).

Figure 2. Target processing efficiency as a function of load (bars indicate standard errors).

Figure 1

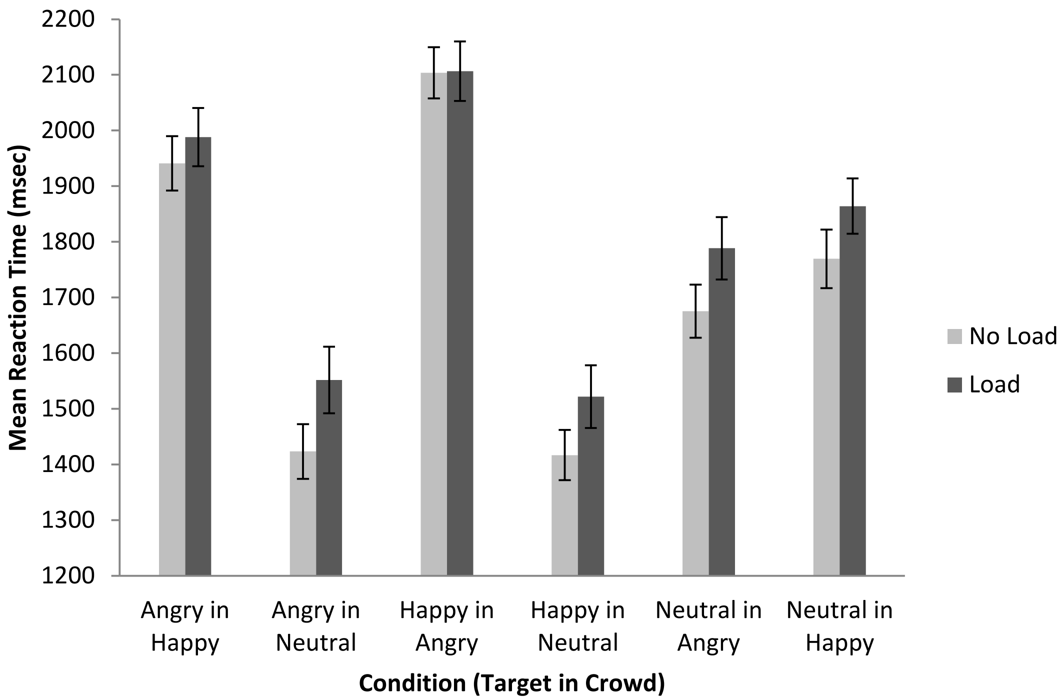
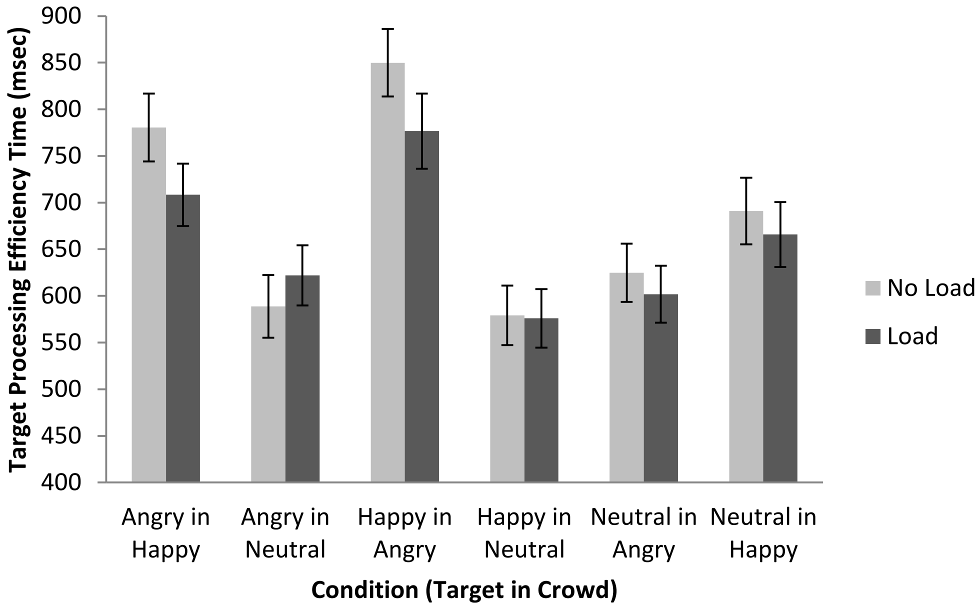

2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
Mean Reaction Time (msec)
Angry in Happy
Angry in Neutral
Happy in Angry
Happy in Neutral
Neutral in Angry
Neutral in Happy
Condition (Target in Crowd)
No Load
Load

Figure 2


900
850
800
750
700
650
600
550
500
450
400
Target Processing Efficiency Time (msec)
Angry in Happy
Angry in Neutral
Happy in Angry
Happy in Neutral
Neutral in Angry
Neutral in Happy
Condition (Target in Crowd)
No Load
Load