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Processing efficiency in anxiety: Evidence from eye-movements during visual search

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Abstract

It is generally held that anxiety is characterized by an attentional bias for threatening information. In recent years there has been an important debate whether these biases reside at the level of attentional selection (threat detection) or attentional processing after threat detection (attentional disengagement). In a visual search task containing emotional facial expressions, eye-movements were examined before and after threat detection in high and low trait anxious individuals to further elucidate the temporal unfolding of attentional bias. Results indicated that high anxious individuals neither showed facilitated orienting to threat nor impaired disengagement of visual attention from threat. Interestingly, the presence of threat in the visual search display was associated with increased decision times in high anxious individuals. These results challenge some of the current views on attentional bias to threat but indicate that emotional information reduces processing efficiency in anxiety.

Keywords: Anxiety, processing efficiency, eye-movement, threat, visual search, attentional bias

Introduction

Cognitive models of anxiety have postulated that biased attentional processing of threatening information is an important characteristic of individuals with elevated risk to develop anxiety disorders (Eysenck, 1997; Mogg & Bradley, 1998). These attentional biases to threat are considered to be crucial cognitive risk factors associated with heightened emotional reactivity and the etiology and maintenance of anxiety disorders. There is overwhelming empirical evidence in support of the notion that anxiety is characterized by attentional biases towards threat related material (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van Ijzendoorn, 2007; Cisler & Koster, 2010). There is also emerging research to support the prediction that attentional bias is causally involved in anxiety (MacLeod, Koster, & Fox, 2009). An important challenge for current research is to better understand the nature of this attentional bias in order to more precisely elucidate the consequences of attentional bias.

An important debate in the literature has focused on the question of whether anxiety is associated with facilitated attentional orienting towards threat or by difficulties to disengage attention from threat (Fox, Russo, Bowles, & Dutton, 2001). Although attentional bias was initially conceived of as a facilitated attentional orienting to threat (Williams, Watts, MacLeod, & Mathews, 1988) this notion was challenged by research using the spatial cueing task (Posner, 1980). In the emotional adaptation of this task a peripheral threat or neutral cue is immediately followed by a target presented at the same or the opposite location of the peripheral cue. This task has been used to examine whether presenting a target at the same location of a threat cue is associated with reaction time benefits (indicated faster orienting towards the location of threat). Moreover, it can be

examined whether threat causes reaction time costs when attention has to be reallocated on trials where the target is presented at the opposite location of a threat cue (impaired disengagement of threat). Studies using this task have shown that anxiety is specifically associated with impaired disengagement from threat and not enhanced attentional orienting (for a review, see Fox, 2004, but see Koster, 2007). However, the spatial cueing task may not be suitable to capture facilitated attentional orienting (e.g., Weierich, Hollingsworth, & Treat, 2008) and potential response confounds could inflate the possibility to find disengagement effects (Mogg, Holmes, Garner, & Bradley, 2008).

Theorists therefore have been inspired to develop more fine-grained models to understand the temporal unfolding of attentional bias for threat in anxiety. One particularly influential model is the attentional control theory (Eysenck, Derakshan, Santos, & Calvo, 2007; Derakshan & Eysenck, 2009) a major development of the earlier processing efficiency theory (Eysenck & Calvo, 1992). A cornerstone of this theory is the distinction between performance effectiveness and performance efficiency. Effectiveness refers to an individual's competence in doing a task (usually measured by response accuracy), and efficiency refers to the amount and the manner in which processing resources are invested in doing the task (usually measured by response latency). This theory predicts that anxiety has a greater impact on performance efficiency of tasks requiring the inhibition functions of the central executive. In inhibition, attentional control prevents attentional resources from being allocated to task-irrelevant stimuli, and in shifting, attentional control is used in a positive way to allocate attentional resources to execute the task relevant to the current goal. In relation to threat processing, the theory claims that anxiety disrupts the balance between stimulus-driven (involved in bottom-up

control) and the goal-directed (involved in top-down control) systems. These two systems are generally thought to interact in their functioning (Corbetta & Shulman, 2002; Pashler, Johnston, & Ruthruff, 2001). Anxiety is believed to increase the influence of the stimulus-driven system over the goal-directed processes, reducing attentional control.

The present study investigated whether attentional bias in anxiety is a reflection of facilitated attentional orienting towards threat or attentional impairments after threat detection. The visual search task provides a useful paradigm to examine attentional capture by threat as well as attentional disengagement. In this task, participants are 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. The visual search task has demonstrated anxiety-related attentional biases both at the level of facilitated attentional engagement to threat (e.g., Öhman et al., 2001; Rinck et al., 2005) as well as impaired disengagement from threat (Byrne & Eysenck, 1995).

One important drawback of most research using this task is that response latencies are used as the only dependent variable. It has been argued that the presence of threat could facilitate behavioral responding, inflating the chance to conclude that anxious

individuals show facilitated attentional engagement with threat (see Flykt, 2006). Others have argued that threat can disrupt behavioral responding which could lead to a higher probability to find disengagement effect (Mogg et al., 2008). Thus, it is possible that manual responses do not provide an accurate index of attentional processes. Moreover, during visual search there may be several shifts of attention *before* as well as *after* target detection that are not indexed by manual response latencies. Therefore, we tracked eye-movements during visual search to obtain a more comprehensive picture of threat processing at levels of both crowd and target. This methodology allowed to examine attentional operations before detection of threat (facilitated attentional engagement) as well as after detection of threat (impaired attentional disengagement).

We used emotional expressions of faces (angry, happy, and neutral) as stimuli in a visual search paradigm. We used angry expressions as there is accumulating evidence to suggest that high anxious individuals compared with low-anxious individuals show an enhanced attentional bias towards angry facial expressions of emotion over other emotional expressions and regard them as personally relevant (see Fox, 2008; Bar-Haim et al., 2007 for reviews). By combining information from manual responding and eye-movements it is possible to examine some of the predictions from the processing efficiency and attentional control theories and to determine whether anxiety is associated with facilitated orienting towards or impaired disengagement from threat. We predicted that threat biases attention through disruption of the inhibition function and thus cognitive processing would be hampered in high anxious individuals upon detection of threat. This would lead to the prediction that behavioral responding will be delayed when threat has captured attention and attention needs to be disengaged from threat. Therefore in order to

examine how threat processing is affected by both target and crowd our method of analysis distinguished between attentional operations *before* and *after* target detection.

Method

Participants

A total of 77 participants (45 female and 32 male) were recruited via advertisements posted in university of london departments. They had a mean age of 31.16 years ($SD = 10.35$). All participants had normal or corrected-to-normal vision and were allowed to wear their glasses or contact-lenses if required. They were paid £5 for their contribution.

Stimuli

The stimulus images were obtained from the Parke-Waters face model (Parke & Waters, 1996; Waters, 1987). This 3-D polygonal representation was deformed to produce different emotional (angry, happy) and neutral facial expressions. The process is applied through a mechanical model of the facial musculature. An expression was determined by the specification of eighteen muscle-activation values (nine left/right pairs). The original model was designed to accommodate the full range of facial expressions described by the FACS system of Ekman and Friesen (Ekman & Friesen, 1978).

Three different expressions were created: angry, happy, and neutral. The muscle activation values were set interactively for each expression, and were consistent with Parke-Waters FACS-validated parameters. The left and right muscles in each pair were given the same activation, resulting in symmetric expressions. The models were

positioned against a black background, with a virtual light-source illuminating the faces evenly¹.

The visual angle subtended by each face, when fixated, was $2^{\circ} 29'$ x $4^{\circ} 29'$. 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 (see Figure 1). 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 $8^{\circ} 15'$.

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. Each stimulus-screen was shown three times, resulting in a total of 144 experimental trials.

The design also incorporated 36 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. 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 6.35mm. 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 6.35mm.

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-tracking device. Participants completed a measure of trait anxiety (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983). They were seated in front of the Eye-gaze system at an approximate viewing distance of 60cm. Participants were instructed to press the response button whenever one of the faces in the display differed from the others, and not to press the button if the display did not contain a face different from the others. 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 10 practice trials. The eye-tracking calibration required participants to fixate a series of twelve points on the screen before the main experimental task began. Participants were thanked and debriefed at the end of the session.

Results

Mean and median trait anxiety scores for the entire sample were 41.62 ($SD = 8.89$) and 42, respectively. Median splits² were used to define participants into low-anxious ($N = 38$) and high-anxious ($N = 39$). Mean trait anxiety for the low-anxious group was 34.34 ($SD = 4.67$) and for the high-anxious group it was 49.60 ($SD = 6.28$), $F(1, 75) = 146.34, p < .001$. Less than 1% of all trials were lost due to erroneous response or eye-tracking failures.

Reaction times and eye-movement indices (see below) were analysed using 6 (Condition) X 2 (Group) Mixed ANOVAs³.

Manual Responding

Manual responses were recorded from the onset of the face array. Less than 2% of the data was lost due to outliers (reaction times less or greater than 3SD of each participant mean). Figure 2 shows that participants were slowest in the conditions where both target and crowd were emotional: an angry target in a happy crowd, and a happy target in an angry crowd. This effect however was greater in the high-anxious than low-anxious group. Analyses confirmed these observations by revealing main effects of Condition $F(5,375) = 162.90, p < .001$, Group $F(1,75) = 5.93, p < .02$, as well as a two-way interaction of Condition X Group $F(5,375) = 4.47, p < .002$. High-anxious compared with low-anxious individuals were slower to respond to an angry target in a happy crowd, $t(75) = 3.03, p < .004$; and to a happy target in an angry crowd, $t(75) = 3.15, p < .003$. No other group comparisons reached significance.

Eye-movement Data

Attentional Operations *Before* Target Detection

Descriptive statistics for the following eye-movement indices are shown in Table 1.

Number of fixations on crowd. This was defined as the number of fixations participants made on crowd faces *before* fixating the target. Participants made more fixations on emotional than neutral crowd faces prior to fixating target. Analyses confirmed a main effect of Condition $F(5,375) = 35.65, p < .001$ but no significant interaction with Group, $F < 1$.

Number of crowd faces fixated. This was defined as the number of crowd faces fixated prior to fixating the target. This index assessed how the crowd faces drew

attention altogether and could be used to test *vigilant scanning*. Participants fixated more crowd faces prior to fixating the target when the crowd was emotional than neutral.

There was a main effect of Condition $F(5,375) = 34.66, p < .001$, but no significant interaction with Group, $F < 1$.

Total time spent on crowd prior to fixating target. This was defined as the time participants spent on the crowd faces prior to fixating the target, i.e., the time it took participants to fixate target from the onset of the visual display. Participants spent more time fixating the crowd faces when they were emotional than neutral, $F(5,375) = 54.89, p < .001$. No significant interaction with Group, $F < 1$ was found.

Mean crowd dwell time. This was defined as the mean time participants spent on *each* individual crowd face before fixating the target. This index was used to assess the attention grabbing power of each face (*attentional dwell-time*). Participants dwelled longer on emotional compared to neutral crowd faces $F(5,375) = 14.24, p < .001$, but no significant interaction with Group, $F < 1$ was found.

Attentional Operations *After* Target Detection

Target processing efficiency. This was defined as the time elapsed between landing the first fixation on target and behavioural reaction time as assessed by button press and was used to assess the time taken to process the target. Figure 3 shows participants took longer to process an angry or happy target when the crowd was also happy or angry, compared to when the target or crowd was neutral, $F(5,375) = 60.12, p < .001$. A two-way interaction of Condition X Group $F(5,375) = 5.88, p < .001$ showed that high-anxious compared to low-anxious individuals were slower to process an angry

target in a happy crowd $t(75) = 3.55, p < .002$ and a happy target in an angry crowd $t(75) = 2.85, p < .008$. There were no significant group differences when either target or crowd was neutral.

Time spent on target. High-anxious compared with low-anxious participants fixated an emotional target face for longer (Figure 4). There was a main effect of Condition $F(5,375) = 14.70, p < .001$ as well as a two-way interaction of Condition X Group $F(5,375) = 3.57, p < .05$.

Number of crowd fixations after fixating on target. This was defined as the number of fixations that participants made on the crowd faces *after* fixating target and shows how much target processing time was devoted to the crowd faces. Participants made more crowd fixations when an angry target was embedded within a happy crowd and a happy target within an angry crowd. Analyses confirmed a main effect of Condition $F(5,375) = 43.14, p < .001$ and a two-way interaction of Condition X Group $F(5,375) = 6.20, p < .001$. Figure 5 shows that high-anxious compared with low-anxious individuals made more fixations on the crowd after fixating on target when an angry target was presented within a happy crowd $t(75) = 2.61, p < .02$ and when a happy target was presented within an angry crowd $t(75) = 2.28, p < .03$. There were no significant group differences when either the target or crowd were neutral.

Discussion

We examined the attentional processes associated with visual search for emotional and neutral target and crowd faces. Related to current debates on the nature of attentional bias in anxiety, we distinguished between attentional processes *before* and *after* threat detection. There were two main findings: First, that anxiety was neither

associated with facilitated attention towards or with impaired disengagement from angry facial expressions prior to target detection; and second, that anxiety was associated with disrupted responding to angry and happy targets on trials that contained an emotional (angry or happy) crowd. These results are relevant to current debates on the nature of attentional bias and are discussed in turn below.

An abundance of empirical research using tasks that rely on manual responding generally indicates that anxiety is characterized by threat-related biases at the level of spatial attention (Bar-Haim et al., 2007). We aimed to further investigate whether such attentional bias was observed before or after threat detection. Surprisingly, none of the eye-movement indices before target detection indicated biases at the level of spatial attention to threat as a function of anxiety. More specifically, emotional crowds were fixated more often than neutral crowds *before* target detection but this effect was not modulated by trait anxiety. Of crucial importance, the speed of fixation on threatening (angry) targets was not modulated by anxiety.

How can the absence of threat-related biases in spatial attention be reconciled with previous research on attentional bias? Most previous studies have not examined attentional processes before and after target detection using eye-movements and reaction times alone do not provide a detailed temporal examination of the nature of attentional bias for threat in anxiety (Weierich et al., 2008). Furthermore, studies that have measured eye-movements have not obtained consistent evidence with regard to the existence of attentional bias to threat. For instance, in the context of visual search findings have been obtained that detection of threat in anxious individuals is facilitated (Rinck & Becker, 2006), disengagement from threat is delayed (Gerdes, Pauli, & Alpers, 2009), or neither

of these processes (Huijding, Mayer, Koster, & Muris, submitted). These discrepant findings may indicate that the phenomenon of attentional bias in anxiety is less systematic than previously considered and is sensitive to different contexts and procedures.

The finding that anxiety was associated with disrupted responding to emotional targets on trials containing emotional information is partially consistent with predictions from attentional control theory (Eysenck et al., 2007). This theory predicts that processing efficiency is impaired upon encounter of threat-related information in high-anxious individuals. Interestingly, impaired processing efficiency was not reflected in a threat-specific impaired attentional disengagement but by an overall disruption in goal-directed target processing, such that anxious individuals required longer decision times from the time they fixated the target to the moment they provided a manual response on trials where target and crowd were both emotional. The eye-movement data indicated that this was due to additional fixations on the crowd *after* the target had been detected. Importantly, this effect was not threat-specific as impaired processing efficiency was not found on all trials containing angry faces but on trials where an angry target was presented in a happy crowd and when a happy target was presented in an angry crowd. All participants were slower on these trial types compared with all other trial types, which suggests that target discrimination from the crowd was most difficult in these conditions. Hence, it could be that emotional information disrupts processing efficiency mainly under conditions of some uncertainty. Alternatively, the emotional information embedded in both target and crowd meant that attentional processes were more heavily taxed by the emotional stimuli, causing reduced processing efficiency.

The present findings have a number of implications for theories and empirical research concerning attentional bias in anxiety. First, it is widely assumed that anxiety-related processing biases are resided at the level of visual attention but the present data shows impairments at the level of target processing. Secondly, the findings indicate that cognitive models of anxiety should consider processing biases that operate among several levels of cognitive processing. Finally, the notion of impaired processing efficiency upon encounter of threat in high-anxious individuals is of interest to the measurement of attentional bias. That is, several commonly used reaction time tasks in attentional bias research have been criticised on potential confounds between attentional processes and behavioral interference (e.g., De Ruiter & Brosschot, 1994), and the present data clearly support the notion that target processing can be delayed by threat without being a reflection of attentional bias at the visuo-spatial level. Obviously, it is not clear whether processing efficiency is hampered under different circumstances (e.g., when less distracting stimuli are present) but potential behavioral interference remains an important concern for reaction time measures of attentional bias (see also Mogg et al., 2008).

There are several ways in which future research should extend the current findings. First, it is important to examine if the results of this study generalize to samples with more specific types of anxiety and clinical anxiety. However, the magnitude of biases in high trait anxiety obtained in a normal population is of similar to that found in clinical anxiety (Bar-Haim et al., 2007). Second, 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 observed on trials with angry faces present. The latter finding suggests emotion processing during visual search instead of a purely feature-based search. Finally, we presented the analyses based on median-split to ensure appropriate statistical power. It is important to emphasize that we replicated the same pattern of findings when we used a tertiary-split on the anxiety scores.

In sum, the current study showed that processing efficiency, but not visual attention, was influenced by the presence of threat in low and high trait anxious individuals. Through combination of eye-movement methodology and manual response latencies a fine-grained analysis could be obtained on threat-processing biases in anxiety. The present methodology may represent an important way forward in understanding the mechanisms underlying biased threat processing in anxiety.

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Footnotes

¹ There are advantages of using a computer-generated face. First, the facial expressions are fully parameterised by the muscle activation values. This means that expressions can be quantified and interpolated in the parameter space. Also, the appearance of the face is likely to be more generic than a photograph of a person. For similar reasons several previous experiments have argued for a preference of schematic over real faces (e.g. Öhman, Lundqvist, & Esteves, 2001; Fox, Lester, Russo, et al., 2000; Tipples, Atkinson & Young, 2002).

² Similar effects for all of the dependent variables of interest were also obtained using tertiary splits.

³ More specific analyses were performed on manual responses and eye-movement data, examining attentional engagement for angry vs. happy targets (in neutral crowd) and attentional disengagement from angry vs. happy crowds (with neutral target). None of these analyses revealed attentional engagement or disengagement effects for threat in high vs. low-anxious individuals

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Figure captions

Figure 1. Example of an angry face in a neutral crowd.

Figure 2. 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 3. Target processing efficiency in low- and high-anxious groups.

Figure 4. Time spent on target in low- and high-anxious groups.

Figure 5. Number of crowd fixations after fixating target in low- and high-anxious groups.

Table 1

Table 1. Patterns of eye-movements prior to fixating target as a function of valence of target and crowd

Eye-movement index	Condition (Target in Crowd)					
	Angry in Happy	Angry in Neutral	Happy in Angry	Happy in Neutral	Neutral in Angry	Neutral in Happy
	<i>M (SD)</i>	<i>M (SD)</i>	<i>M (SD)</i>	<i>M (SD)</i>	<i>M (SD)</i>	<i>M (SD)</i>
<i>No. of crowd fixations</i>	2.90 (0.88)	2.32 (0.78)	3.18 (0.78)	2.43 (0.75)	2.95 (0.86)	2.97 (0.80)
<i>No. of crowd faces fixated</i>	2.66 (0.68)	2.14 (0.66)	2.91 (0.68)	2.27 (0.66)	2.69 (0.70)	2.71 (0.71)
<i>Time (ms) spent on crowd faces</i>	578.48 (187.22)	434.85 (167.64)	645.63 (182.61)	463.67 (174.28)	596.81 (194.50)	585.89 (181.39)
<i>Crowd attentional dwell time (in ms)</i>	193.85 (22.81)	182.36 (20.40)	201.83 (32.94)	186.70 (23.02)	198.19 (23.95)	194.28 (23.42)

Fig 1

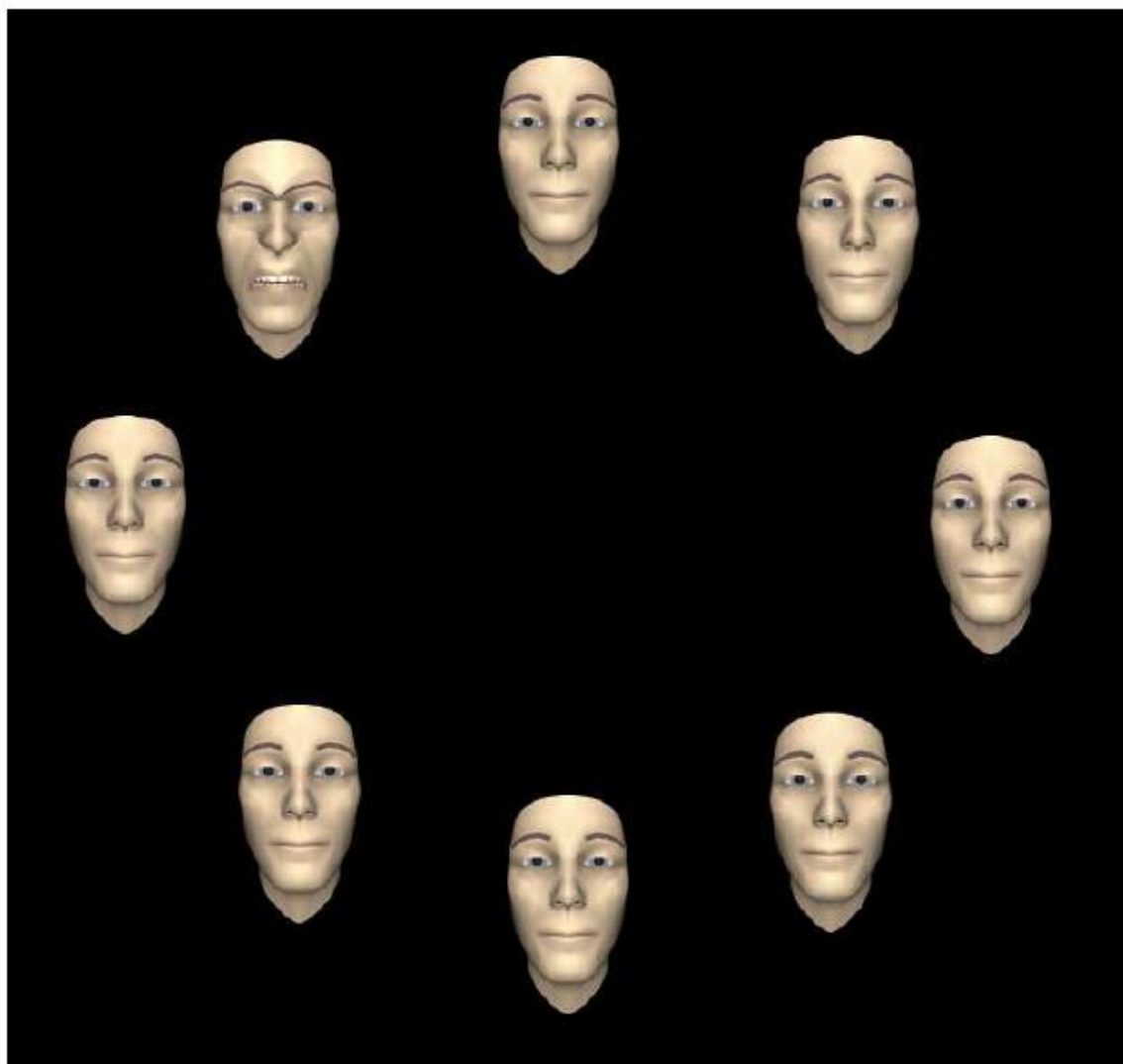


Fig 2

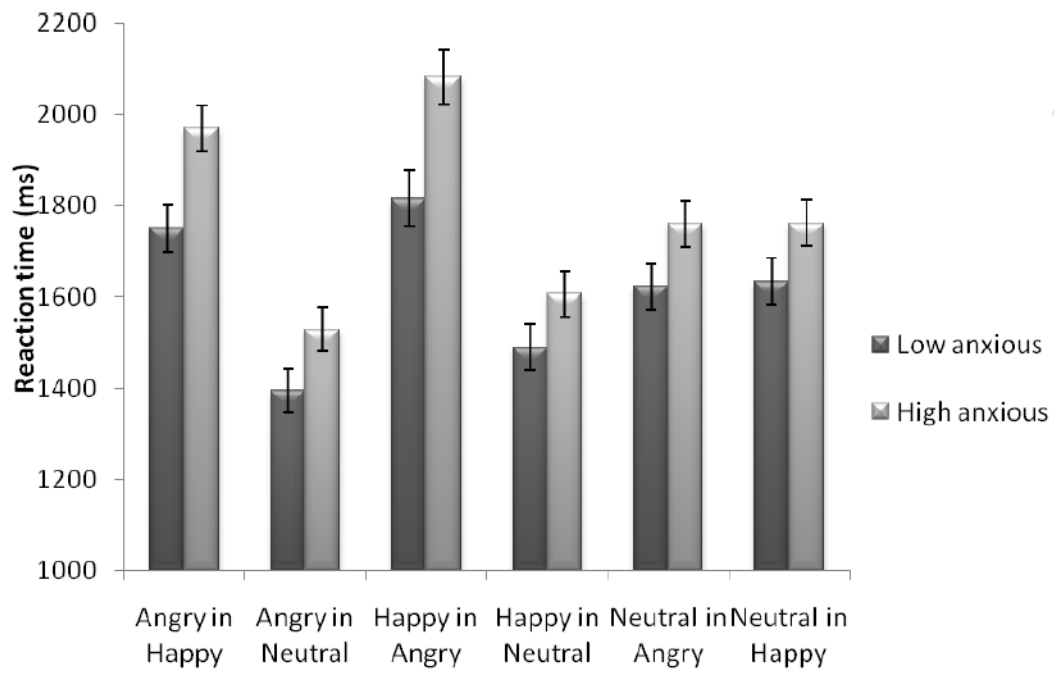


Fig 3

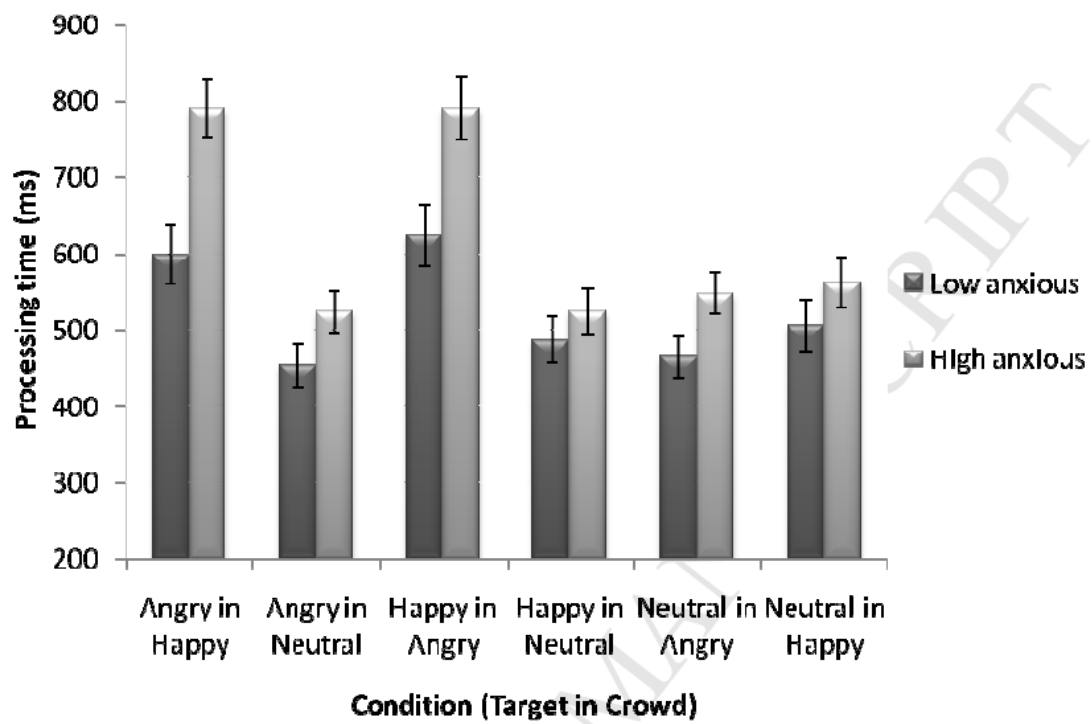


Fig 4

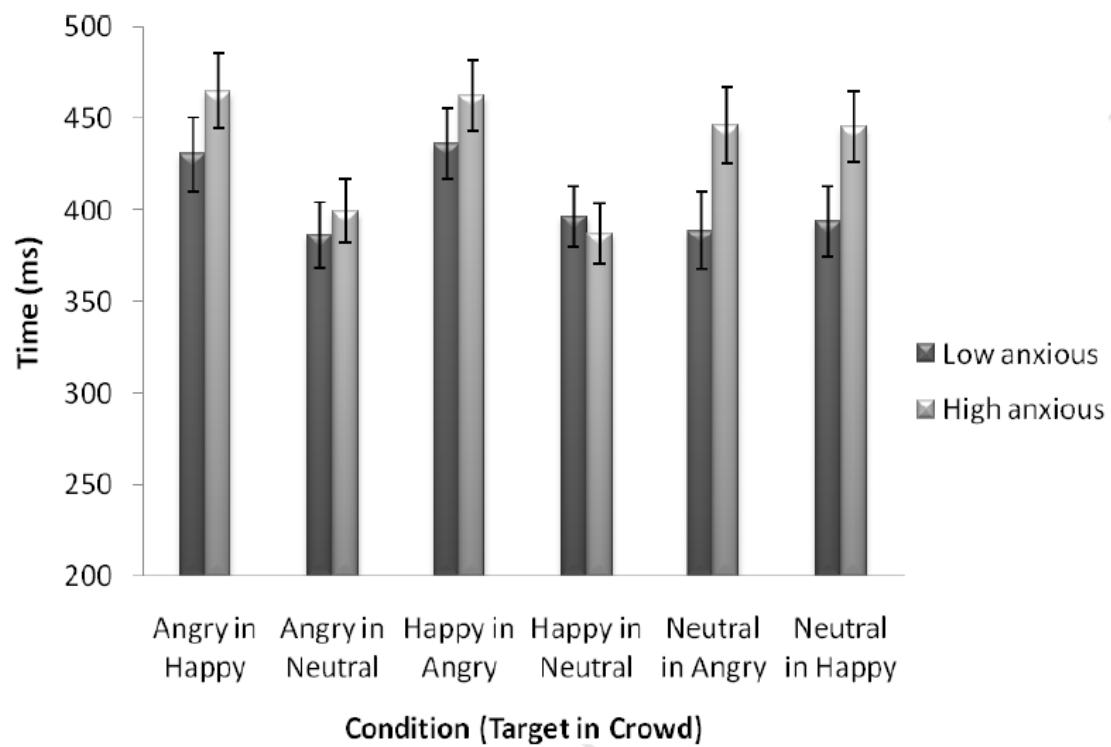


Fig 5

