View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by Birkbeck Institutional Research Online

BIROn - Birkbeck Institutional Research Online

Berggren, Nick (2020) Rapid attentional biases to threat-associated visual features: the roles of anxiety and visual working memory access. Emotion , ISSN 1528-3542. (In Press)

Downloaded from: http://eprints.bbk.ac.uk/31039/

Usage Guidelines:
Please refer to usage guidelines at http://eprints.bbk.ac.uk/policies.html or alternatively contact lib-eprints@bbk.ac.uk.

Rapid attentional biases to threat-associated visual features: The roles of anxiety and visual working memory access

Nick Berggren

Department of Psychological Sciences, Birkbeck College, University of London,

Malet Street, London WC1E 7HX, UK

Phone: 0044 20 76316522

Fax: 0044 20 76316312

Email: nbergg01@mail.bbk.ac.uk

ABSTRACT

Threat-related information strongly biases attention, particularly for high anxious individuals. It is less clear though what the consequences of attentional capture by threat are, and how this influences subsequent visual processing. This study examined how capture by threat influences visual search when attributes related to a threat reappear as task-irrelevant information. In Experiment 1, participants completed a search task preceded by task-irrelevant face cues on each trial expressing neutral, happy, or angry emotions. Faces were filtered to appear in different colors, where this color could match a non-emotional distractor object in the upcoming search display. While the color of neutral/happy face cues had no impact on performance, there was evidence that angry face colors delayed reaction times when this color reappeared, driven by a positive correlation between costs and individual differences in trait anxiety. Experiment 2 assessed whether this phenomenon would be more readily observed when designating face cues task-relevant. When participants attended to and memorized faces for occasional probe trials, color biases were now evident irrespective of the emotional valence of face cues and unaffected by trait anxiety levels. These results suggest that task-irrelevant threat stimuli are granted privileged depth of processing by high anxious individuals, triggering biased attention towards features related to this object. Such biases are not dependent on threat per se, occurring for other objects voluntarily processed to similar depth regardless of personality factors. This highlights that anxiety-related phenomena, such as delayed disengagement of spatial attention from threat, may stem from task-irrelevant visual working memory representation.

Keywords: Emotion; Selective attention; Threat bias; Trait anxiety; Working memory

INTRODUCTION

Selective attention enables individuals to focus on certain information in lieu of other signals. Which stimuli ultimately receive attentional priority is seen to depend on both top-down factors, such as stimuli that match the content we are actively looking for, but also bottom-up factors, such as highly salient stimuli that are able to capture attention despite being potentially task-irrelevant. This dichotomy however may be too simplistic, as attention can also be rapidly allocated to information that seems neither relevant to our current goals nor physically salient (e.g., Awh, Belopolsky, & Theeuwes, 2012). A prime example of this point comes from the observation that motivationally-salient stimuli, particularly threat-related cues, are able to strongly compete for selection. Threat-related target objects are more readily detected during visual search (e.g., Ohman, Flykt, & Esteves, 2001), and task-irrelevant threat conversely causes pronounced costs to performance efficiency (e.g., Algom, Chajut, & Lev, 2004).

While the guidance of attention by threat-related information could be interpreted as a hardwired response in the visual system to rapidly process certain complex objects that denote danger (see e.g., Gomes, Soares, Silva, & Silva, 2018, for an example of snake images), such a mechanism has proved controversial (see e.g., Gayet, Stein, & Peelen, in press). Moreover, the ubiquity of rapid biases in visual attention to threat has been challenged by the observation that they appear to readily occur only for certain individuals. Much evidence of threat-related biases in attention comes from studies that have assessed particular anxious populations, such as individuals with specific phobias, clinically anxious groups including those with Generalized Anxiety Disorder or Social Anxiety Disorder, and individuals high in anxious personality traits (see Bar-Haim, Lamy, Pergamin, Bakermans-

Kranenburg, & IJzendoorn, 2007; Cisler, Bacon, & Williams, 2009, for reviews). The consensus from such work is that biases in attention towards threat are pronounced in anxious groups, mainly demonstrated by reduced ability to ignore threat-related distractors in selective attention tasks (e.g., Williams, Mathews, & MacLeod, 1996; Rudaizky, Basanovic, & MacLeod, 2014). While this could be viewed as evidence that threat biases are simply exacerbated within anxious populations, there is in fact weak evidence to suggest that individuals characterized by low levels of anxiety exhibit any attentional bias to threat at all (see Bar-Haim et al., 2007, for meta-analysis). This highlights that prioritization of threat-related signals in the visual environment strongly depends on personality factors, spurring the question why anxious individuals demonstrate such attentional biases. Proposed theoretical accounts have emphasized that these could stem from enhanced pre-attentive processing of threat which interacts with one's internal anxiety level to elicit capture (e.g., Williams, Watts, MacLeod, & Mathews, 1988; Mogg & Bradley, 1998), or that anxious individuals may at some level, explicit or implicit, hold a motivation or goal to detect potential danger in the environment and actively attend to confirmatory signals (e.g., Eysenck, 1992; Wells & Matthews, 1994; Matthews & Wells, 2000).

Regardless of the disagreement over the precise mechanisms underpinning rapid attentional biases, all models can accommodate the finding of enhanced attentional capture by threat among anxious individuals. Far less research, however, has examined what the consequences of these biases in attention are; anxious individuals appear to rapidly allocate selective attention to threat, but what implication does this have if any to subsequent visual attention processing? One well-documented consequence of attentional capture by threat is a subsequent difficulty in successfully disengaging spatial attention from it towards other stimuli (e.g., Fox, Russo, & Dutton, 2002; Koster, Crombez, Verschuere, Van Damme, &

Wiersema, 2006; Sheppes, Luria, Fukuda, & Gross, 2013), suggesting that attended threat stimuli are not just prioritized when competing for attention but are also able to 'hold' attention post-capture. This results in costs to other stimuli, such as discrimination ability for objects at other locations being impaired when attention is occupied at the location of a threat stimulus (Ferneyhough, Kim, Phelps, & Carrasco, 2013).

If anxious individuals not only rapidly attend to threat, but also subsequently 'hold' and continue selectively processing this information, this suggests a disruption to attentional processing and a prolonged prioritization of a threat stimulus. This could stem from anxious individuals not only being drawn to threat, but narrowing in spatial attention when a threat is detected (see Easterbrook, 1959; Eysenck, 1992). Another possibility is that, once threat captures spatial attention, inhibition is required to discontinue and withdraw attention from its location, a process that may generally be impaired among highly anxious individuals (e.g., Fox, 1994; see also Eysenck, Derakshan, Santos, & Calvo, 2007). These accounts can explain why spatial attention to other visual information is impaired following the processing of threat, as attention remains fixated at the location of the threat. However, such emphasis on the role of spatial attention also implies that threat processing is somewhat superficial; threat draws spatial attention to its location and this is subsequently difficult to override, but there is little speculation regarding what narrowed spatial attention to threat might confer other than to merely expedite alerting an individual to the location of a danger.

If attention is preferentially allocated to and held by threat, what other consequences can be observed? It is well-established that attention is capable of being applied in both a spatial fashion and non-spatially by basic features (e.g., color; shape;

orientation; size). This is vital in situations such as visual search, where by definition the location of an object being searched for is not known in advance, and efficient guidance of attention can only be based on known characteristics of the target object (e.g., Duncan & Humphreys, 1992; Wolfe, 2007). Selectivity on the basis of features results in biases of attention towards any features that match the current search goal, which for example when searching for a red letter can result in distraction by other task-irrelevant red stimuli but not blue or green items (e.g., Folk, Remington, & Johnston, 1992; Folk, Leber, & Egeth, 2002). Importantly, feature biases can also operate independently to spatial influences on attention, where for instance knowing that a red target item can only appear at a particular location does not necessarily prevent attentional capture by irrelevant red items at other locations (e.g., Berggren, Jenkins, McCants, & Eimer, 2017; Martinez-Trujillo & Treue, 2004; Serences & Boynton, 2007).

As feature-based attention is believed to generally operate in a spatially-global manner (but see Leonard, Balestreri, & Luck, 2015), selectively processing a threatening stimulus could narrow or prioritize not only spatial attention to the item's location, but also feature-based attention to the threatening object's content. As a result, selective attention to these features would increase the likelihood that other objects in the environment sharing these features, even at other locations, compete for attention; effectively an 'associative threat bias' towards threat-related features. If this is the case, it provides implications that biased attention to threat involves not only a superficial biasing of spatial attention to a threatening object's location, but also that such objects' features are heavily prioritized and can elicit additional biases to other objects related to the threat stimulus' attributes. To examine this, the present study employed a visual search task where participants were asked to locate a target on the basis of its orientation (i.e., a square with a gap in its top or bottom side, presented among non-target squares with left/right gaps). All items in these search displays were presented in different colors, though this was unrelated to the participants' primary task. Prior to each search display, a pair of face cues were presented, expressing neutral, happy, or angry emotions. Importantly, these face cues were filtered to appear in different colors, and on half of trials this color appeared as a non-target square in the subsequent search display (color-present trials) or did not appear (color-absent trials). In Experiment 1, these face cues were irrelevant to the task at hand, and participants were simply instructed to ignore them.

If threat strongly competes for selection, angry faces would be expected to capture spatial attention. This could be reflected by a general main effect of face cue valence on performance, as there is some evidence that threat image cues may generally slow participant response time to immediately succeeding stimuli (e.g., Wilkowski & Robinson, 2006). However, other work using specifically threatening face cues have not shown any general reaction time cost in selective attention tasks (e.g., Berggren & Derakshan, 2013). Importantly though, if attentional capture by threat not only narrows spatial attention but also involves prioritization in feature-based attention, the incidental color of threatening faces should become prioritized in a spatially-global manner, resulting in new objects containing this color competing for attentional selection and causing performance costs when presented as an irrelevant object in search displays. Moreover, given that threat biases in attention have been suggested to occur only for individuals reporting high anxious personality traits (Bar-Haim et al., 2007), this effect would be expected to be modulated by participants' trait anxiety levels.

EXPERIMENT 1

Method

Participants

Fifty-eight participants were initially recruited to participate in the study via online advertisement. Of these, two participants were excluded and replaced with new participant data due to performance at chance-level accuracy in one or more conditions. Of the final sample (*M* age = 26 years, SD = 6; 24 male; all right-handed), all participants reported normal or corrected-to-normal vision. All study procedures involving participants were approved by the departmental ethical committee.

To determine the desired sample size, the correlation coefficient associated with a previous study demonstrating a significant relationship between selectivity in spatial attention following a threat stimulus and trait anxiety was utilized ($r = .36$; Ferneyhough et al., 2013). Analysis using G*Power software (Faul, Erdfelder, Buchner, & Lang, 2009) suggested that, assuming a model of equal predictive strength for feature-based selectivity, a sample size of 58 participants was necessary with an alpha level of .05 and power of 0.8 to demonstrate a similar relationship.

Stimuli and Procedure

The experimental task was programmed and executed using E-Prime 2.0 software (Psychology Software Tools, Inc.). Participants sat at a viewing distance of approximately 90 cm. All stimuli were presented on a black background, with a small grey fixation cross appearing constantly throughout a block. Face stimuli consisted of eight identities (4 male), each displaying a neutral, happy, or angry expression. Six face identities were taken from the NimStim database (Tottenham et al., 2009) and two from the Ekman and Friesen (1976) database. All face stimuli were cropped using an oval template so that only the face was visible, and measured 1.59 x 2.55° of visual angle. Two identical stimuli were presented on each trial either side of fixation at an eccentricity of 1.91° measured from fixation to the outer edge of each face. Face stimuli were filtered from greyscale to add color tints: red (CIE coordinates: .605/.322), orange (.543/.409), green (.296/.604), blue (.169/.152), and magenta (.270/.134). Search display objects (0.89 x 0.89°) were square boxes, each containing a small gap (0.13°) in one of their sides. The target contained a gap in its top or bottom side, and non-targets left or right side. Objects were presented at the four cardinal points from fixation at an eccentricity of 0.95° measured from fixation to the edge of the object, and could appear in the same colors as the filters used for face stimuli at the same RGB values. All colors were matched for luminance (14 cd/m^2). To measure individual differences in trait anxiety, participants completed the State-Trait Anxiety Inventory (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983), which measures self-reported ratings of anxious disposition and mood. This questionnaire is widely used in the literature and has good validity and reliability.

Participants completed the anxiety questionnaire prior to the experimental task. Each block began with an initial 1000 ms blank screen period before the start of the first trial. Each trial began with a face cue display (50 ms), followed by a 750 ms inter-stimulus interval. Search displays were then presented for 150 ms followed by a further 1850 ms blank screen, creating a 2000 ms response window. Participants were told that face cue displays could show faces of different genders, expressions, and were filtered to appear in different colors, but that both faces shown in a display would be identical. They were instructed to ignore the face images and maintain fixation. When the search display appeared, they were tasked to locate the object with a gap in its top or bottom side, responding by pressing the ‘2’ or ‘0’ key on the numeric keypad respectively, as quickly and as accurately as possible.

Insert Figure 1 about here

Following practice, participants completed four experimental blocks of 60 trials each. Trials within each block were randomly selected from a counterbalanced list of 240 trials. This counterbalanced face cue expression (3), face identity (8), face color (5), and color presence (2). Target location and orientation were randomized. On color-present trials, the color of the face cue reappeared in search displays as a non-target object along with three other randomly chosen colors. On color-absent trials, the color of the face cue did not appear in search displays and the four remaining colors were randomly allocated to the target or non-target objects.

Results

Insert Table 1 about here

Within-subjects: Table 1 presents mean reaction time data from correct-response trials along with error rate percentages for each experimental condition. Reaction time data were entered into a 3x2 Analysis of Variance (ANOVA) with the factors Face Expression (Neutral, Happy, Angry) and Color Presence (Present, Absent). This showed no significant main effect of Face Expression ($F(2,114) = 1.05$, $p = .35$) or Color Presence ($F(1,57) = 1.19$, $p = .28$). There was, however, a trend for a two-way interaction ($F(2,114) = 2.36$ $p = .099$, $\eta p^2 = .04$, 95% CI [.00, .12])[1], which suggested that a color presence effect was more evident following angry face cues (*M* diff = 15 ms) than following neutral or happy face cues (*M* diff = -5 & 4 ms). A matching ANOVA analysis of error rate data also showed no reliable main effects (*F*'s < 1) or interaction ($F(2,114) = 1.19$, $p = .31$).

Trait anxiety: To assess whether any biases were related to trait anxiety, trait anxiety score (TAS) was added as a covariate factor within the ANOVA model. This showed no significant three-way interaction between Face Expression x Color Presence x TAS ($F(2,112) = 1.36$, $p = .26$)[2]. Given the a priori hypothesis however and sample size calculation based on a predicted correlation between TAS and color presence costs following angry face cues, correlations were conducted on color presence effects for each face expression level. There was no association between trait anxiety level and color presence effects following neutral ($r < .10$) or happy ($r = .199$, N = 58, $p = .13$) faces. Following angry faces, however, there was a significant positive correlation between trait anxiety level and color presence costs ($r =$

[1] Note that, if collapsing RTs on neutral and happy expression trials to conserve statistical power, this interaction was significant at an alpha level of .05, ($F(1,57) = 4.56$, $p = .04$, $\eta p^2 = .07$, 95% CI [.00,.22]). Color presence costs following an angry face cue were statistically reliable (*M* diff = 15 ms; $t(57) = 2.35$, $p = .02$, $d = .44$, 95% CI [.06, .81]), whereas no cost was evident following a non-threatening face cue (*M* diff = 0 ms; $t < 1$).
[2] Similar to the main ANOVA analysis, collapsing neutral and happy expression trials resulted in evidence for a three-way interaction with TAS ($F(1,56) = 3.04$, $p = .04$, one-tailed).

.382, N = 58, p = .003; see Figure 2). There were no associations between anxiety level and error rate validity effects (r's < ±.10).

Insert Figure 2 about here

Discussion of Experiment 1

Across the sample as a whole, the results of Experiment 1 provided weak support for the hypothesis that the capture of attention by threat would elicit biases in feature-based attention to threat-associated color features. While there was evidence for a color presence cost following angry face cues, with slower RTs when the color of this face reappeared as a non-target object in search displays, and little evidence for this following neutral or happy face cues, the interaction between color presence and face expression was marginal. However, there was evidence to suggest that this modest overall relationship was due to strong individual differences related to participants' trait anxiety levels. When examining this, trait anxiety scores positively correlated with color presence costs following angry face cues. This supports previous evidence that biases in attention related to threat may be critically dependent on individual differences in trait anxiety (Bar-Haim et al., 2007). Findings additionally suggest that biases in attention towards threat may not only result in prioritization of spatial attention to the location of a threat stimulus, but can equally elicit prioritization of a threat object's attributes at the level of feature-based attention, resulting in additional biases towards these features comprised within a new object even when this object is not itself threatening. Indeed, it is notable that the effect size of the threat-associated color bias observed in relation to anxiety was almost exactly as predicted when using a previous study that examined biases in spatial attention as the basis for a priori power estimation (Ferneyhough et al., 2013, where r = .36 vs. r = .38 in the current experiment). This suggests that, following the capture of attention by threat, processing of this stimulus and its constituent features becomes prioritized at the level of selective attention in a similar manner to prioritization observed in spatial attention.

Based on Experiment 1's results, a key question is why color presence costs following an angry face cue were mainly driven by individual differences in trait anxiety, as opposed to occurring across the sample at a similar magnitude. One possibility is that, if anxiety predicts to what extent a task-irrelevant threatening face cue will capture attention to begin with (Bar-Haim et al., 2007), individuals at lower trait anxiety levels may simply be better able to ignore these initial cues thereby precluding any association forming between the affective object and its color feature value. On the basis of this account, all individuals in principle could show a strong and rapid bias in attention towards threat-associated color objects provided initial threatening cues do capture attention and are not ignored. A second possibility is that, as face cues were presented alone before the visual search display, all participants may have allocated attention to the face cues, but trait anxiety predicted whether or not an active association was formed between the threatening stimulus and its color that would lead to a rapid associated bias in attention. In other words, anxiety may be the crucial factor in the formation of the threat-color association in order to subsequently bias attention.

The goal of Experiment 2 was to examine these possibilities. Participants completed a similar visual search task as in Experiment 1, but were now asked to actively attend to and memorize the identity of face cues. On 2/3 of trials, following the presentation of face cues, visual search displays appeared as in Experiment 1, and participants were instructed to find the target object and discard the memorized face cue information. On the remaining 1/3 of trials though, instead of being presented with a search display, participants were shown a probe display containing either an identical or different face cue identity, and were asked to respond to whether the probe identity was a match or mismatch. As face images were now task-relevant, there was no incentive to ignore angry face cues, therefore allowing a test of whether or not threat-associated color biases in attention may be elicited regardless of the influence of trait provided initial threat cues engage attention. If this is the case, a clear color presence cost following angry face cues should be evident across the sample, and there may now be no evidence for a modulation by trait anxiety. Alternatively, if associative attentional biases depend not only on the engagement of attention and encoding of face cues but also on the formation of an active association between the threatening object and the color feature, then it is possible that effects might again be mainly driven by individual differences in trait anxiety.

EXPERIMENT 2

Method

Participants

Fifty-eight participants were initially recruited to take part in Experiment 2. Six participants though were excluded and replaced with new participant data due to average accuracy in the search task falling below a training threshold of 75% (see below). This gave a final sample of 58 participants in line with Experiment 1 (*M* age = 24 years, SD = 5, 14 male; 9 left-handed). All participants reported normal or corrected-to-normal vision.

To determine sample size, the key finding of Experiment 1, a positive correlation between trait anxiety and biased attention to threat-associated color objects (r = .382), was used for power analysis. Achieved power in Experiment 1 was 0.85, and so was well-powered. For sake of comparison between experiments, the same sample size as Experiment 1 was used in Experiment 2.

Stimuli and Procedure

Stimuli and procedure matched Experiment 1, with the following exceptions. Only neutral and angry face cues were used in this experiment. Each trial began with a face cue display, followed by the inter-stimulus interval. On two-thirds of trials, search displays were then presented as in Experiment 1. On the remaining one-third of trials, however, a memory probe display was presented. This was similar to the face cue display except that the faces shown appeared in grayscale. While the probe face always presented the same neutral or angry expression as the cue faces, the identity of the stimulus could match or mismatch the identity shown in the cue display. Participants responded to the probe stimulus by pressing the ‘a’ or ‘s’ key on the keyboard with their left middle and index fingers respectively. Participants were instructed that, following the presentation of the face cue, they would on each trial either be tested on their memory or be presented with a search display, which designated that information held in memory could be discarded. Both tasks were emphasized for speed and accuracy, though participants were made aware that search displays were more likely to occur across trials than memory probe displays.

Due to the dual-task procedure of this experiment, pilot testing showed that performance in the search task suffered. Participants therefore completed a training phase prior to completing the main experiment. They first completed training where all face cues were followed by search displays. They then completed additional practice where all trials contained memory probe displays. Finally, they practiced short blocks of both tasks together until they scored above a threshold 75% average accuracy in search performance. As face cues were presented briefly, memory performance was anticipated to be poor and so average performance did not inform training, provided participants responded on all trials. Following the completion of practice, participants completed four experimental blocks each containing 60 trials. This followed a similar structure to Experiment 1, except that happy face cue trials were now effectively replaced with memory probe trials (i.e., 80 in total). These were equally likely to probe memory for neutral or angry face cues, and was also counterbalanced to the prior cue's face color (5) and identity (8).

Results

Memory test: As anticipated, memory performance in the task was generally poor given the short exposure duration, with average error rates of 39 % in a two-alternative forced choice response. Nevertheless, error rates were significantly lower than chance for both neutral and angry faces (t's > 4.90, p's < .001). Directly comparing neutral and angry face memory scores, there was no significant difference on error rates (*M* = 40 vs. 38 %; *t*(57) = 1.09, *p* = .28).

Insert Table 2 about here

Search test: Table 2 presents mean reaction time and error rate data across each condition. Reaction times were entered into a 2x2 ANOVA with the factors Face Expression (Neutral, Angry) and Color Presence (Present, Absent). This showed no significant main effect of Face Expression ($F < 1$). However, there was a significant main effect of Color Presence ($F(1,57) = 5.04$, $p = .03$, $\eta p^2 = .08$, 95% CI [.00, .23]), indicating that RTs were generally slower on color-present versus absent trials (*M* = 810 vs. 798 ms). Importantly though, while there was a tendency for larger color presence effects following angry (*M* diff = 16 ms) versus neutral (*M* diff = 7 ms) face cues, there was no evidence for a reliable Face Expression x Color Presence interaction ($F(1,57) = .65$, $p = .43$). A matching analysis of error rate data showed no significant main effects or interaction (all *F*'s < 1).

Trait anxiety: Entering TAS within an ANCOVA model showed no significant interaction with Face Expression and Color Presence ($F < 1$). Correlating trait anxiety score with color presence effects showed no significant association following neutral ($r = .127$, N = 58, $p = .34$) or angry ($r = .083$, N = 58, $p = .54$) face cues. Likewise, there was also no association on error rate data following neutral ($r = -.188$, N = 58, $p = .16$) or angry ($r = .097$, N = 58, $p = .47$) face cues. Finally, anxiety score did not predict error rates in face memory for either neutral ($r = .093$, N = 58, $p = .49$) or angry ($r = -.034$, N = 58, $p = .80$) stimuli.

Discussion of Experiment 2

Experiment 2 showed a very different pattern of results compared to Experiment 1. By making face cues task-relevant and requiring memory encoding due to occasional test probes, there was no within-subjects evidence of a specific cost by color objects related to a preceding threat stimulus, and nor was there evidence of an association with trait anxiety. Instead, there was now a general color presence cost, with RTs slower when the color of a face cue reappeared as a non-target object within search displays. Critically, this cost was not significantly affected by the emotional valence of the face cue. Note that as exposure durations and procedures were similar to those in Experiment 1, this result is extremely unlikely to be due to any low-level visual priming of a face cue's color. Results instead suggest that actively attending to and encoding face cue stimuli into visual memory was sufficient to elicit a color-associated bias in attention, even when the initial cue stimulus was not threatening. This implies a role of the depth of processing that an initial cue enjoys in order to determine associative attentional biases, rather than a cue's threat value per se. This is discussed in further detail below.

GENERAL DISCUSSION

The goal of the present study was to examine the consequences that attentional biases to threat may have on subsequent attentional selection. Previous evidence has shown that objects holding threat value strongly compete for and rapidly bias attention to their location (e.g., Ohman et al., 2001; Algom et al., 2004). However, the consequences of this process are poorly understood, with one of the only well-documented phenomena being a subsequent delayed disengagement of spatial attention from a threatening object post-capture (e.g., Fox et al., 2002; Koster et al., 2006), implying that spatial attention is not only drawn to a threatening object but also becomes heavily prioritized and ‘held’ at that location. The present study examined whether a similar process could occur non-spatially for threat-related visual features, assessing whether processing threat would equally result in a narrowing or increased prioritization of attentional selection related to the object’s features. This, in turn, could influence subsequent biases in attention to prioritize new objects in the environment that match these features. This hypothesis was supported in Experiment 1 in that individual differences in trait anxiety, noted to be a critical determinant in eliciting attentional biases to threat (Bar-Haim et al., 2007), were positively correlated with attentional biases towards threat-associated color features. In other words, the higher one’s trait anxiety level, the more strongly a task-irrelevant green angry face resulted in slower subsequent RTs to a target when presented alongside a green non-target object, demonstrating a rapidly-formed attentional bias to threat-associated visual features. In Experiment 2, it was assessed whether the role of trait anxiety in this phenomenon was due to increased initial capture by threat-related stimuli or due to a formed association between threat and color features. By making face cues task-relevant and requiring encoding and maintenance in visual memory, a color bias in attentional selection now occurred unrelated to differences in trait anxiety levels. Crucially though, this effect also occurred regardless of the emotional expression conveyed by the face cues. This suggests that color-associated attentional biases occur following the depth of processing an initial cue receives, and not from the threat value of the cue or one’s trait anxiety level per se.

It is important to note that associative biases in attention, and particularly related to threat-associated information, are in and of themselves not a new result. Much work has shown that evaluative conditioning can lead to a change in the affective value of a stimulus via repeated association (see e.g., De Houwer, Thomas, & Baeyens, 2001). Moreover, it has previously been shown that color stimuli can be conditioned to be associated with threat when predictive of a physical danger, such as an electrical shock, resulting in attentional biases towards this color even when it is no longer predictive of danger (e.g., Notebaert et al., 2010; 2011; 2013; see also general reviews on fear conditioning, e.g., Lonsdorf et al., 2017). However, in these previous studies, associations are learned across repeated exposures, whereas in the present study the color of face cues was randomly changed each trial. These results therefore demonstrate a rapid and transient mechanism, occurring on a single-trial basis, towards the color related to an initial face cue. However, the finding in Experiment 2 that memorized face cues elicited an associated color bias in attention regardless of the face cue's emotional valence suggests that the mechanisms underlying the findings in the current study are not due to evaluative associations with threat per se.

Rather, results suggest that attending to an object and encoding it into visual working memory is sufficient to elicit a bias in attention towards features related to that object. This complements previous evidence that specifically the contents of visual working memory can rapidly guide visual attention. For example, if participants encode a green object in visual working memory and, while retaining this information, are presented with a separate visual search task, task-irrelevant green objects in this display cause a distractor cost to response times (e.g., Soto, Heinke, Humphreys, & Blanco, 2005; Soto, Hodsoll, Rotshtein, & Humphreys, 2008). Moreover, event-related potential markers associated with visual working memory representation are observed in response to cued features designating targets for upcoming visual search displays (Carlisle, Arita, Pardo, & Woodman, 2011), implying that feature biases are coordinated in visual memory, and loading visual working memory processes disrupts feature-guided attention (e.g., Woodman, Luck, & Schall, 2007; Berggren & Eimer, 2018).

This account can accommodate not only the finding in Experiment 2 that encoded face cues biased subsequent attention to distractors matching the color of these cues, but also the results of Experiment 1. The finding that high anxious individuals were susceptible to a threat-associated color bias in attention could be explained if assuming that anxious individuals not only prioritize attention to a threatening face object, even when it is task-irrelevant, but also actively encode this information into visual working memory. This account is supported by previous observations that the presentation of task-irrelevant threat not only interferes with the encoding of task-relevant objects within visual working memory tasks, but also appears to itself be readily maintained in visual memory as reflected by event-related markers of visual working memory maintenance during short retention intervals (e.g., Stout, Shackman, & Larson, 2013; Stout, Shackman, Pedersen, Miskovich, & Larson, 2017). This suggests that anxious individuals show a tendency to deeply process an encountered threat object, even when this is task-irrelevant, which can therefore give rise to subsequent attentional biases to visual features forming part of this object. However, this was not the case in Experiment 2, where no association between trait anxiety level and color presence costs following angry face cues was observed. The crucial change in Experiment 2, whereby face cues were made task-relevant and required memorization, encouraged all participants to deeply encode face cues. This likely eliminated the effect of trait anxiety as observed in Experiment 1, as in that case anxiety was associated with task-irrelevant encoding of threat-related objects, whereas making face cues task-relevant produced ceiling levels of encoding regardless of anxiety and the affective value of the cues.

This account raises the implication that other phenomena observed in anxiety may potentially stem from a similar cause. Specifically, the finding that anxious individuals also show a delayed disengagement of spatial attention following capture by a task-irrelevant threatening object could feasibly be a consequence of task-irrelevant visual working memory encoding of threat-related objects in the visual field. Indeed, when memorizing a visual object, this is believed to involve sensory recruitment mechanisms where visual information is represented in a spatiotopic fashion (e.g., Franconeri, Alvarez, & Cavanagh, 2013), with active maintenance controlled by attention to specific locations. In this sense, the processing of task-irrelevant threat in anxiety may lead to irrelevant visual working memory encoding, which can both impede the disengagement of spatial attention and disengagement from threat object attributes at the level of feature-based attention. This conclusion also has implications to the terminology used to operationalize attentional differences in anxious populations. Based on classic work on arousal and visual attention (e.g., Easterbrook, 1959), attention in anxiety has been described as being ‘narrowed’ towards threatening objects, or ‘broadened’ when discussing threat vigilance behavior (e.g., Eysenck, 1992), placing heavy emphasis on spatial factors. The present study suggests that the general terms of ‘decreased’ or ‘increased’ attentional selectivity are perhaps more fitting, as biases in attention related to threat in anxiety can equally occur within non-spatial aspects of attention, and to new objects at alternative locations to that of an initial threat object in the visual field.

It is notable that in Experiment 2 of the current study, encoding a face cue into visual working memory was sufficient to elicit a bias in attention towards cue-matching color objects regardless of cue emotional expression or anxiety. Previous investigations have found that while information currently held in visual working memory can guide subsequent attention, this is usually dependent on the task-relevance of the specific features currently being maintained, with only active features from an object encoded into working memory rapidly guiding attention (e.g., Olivers, Meijer, & Theeuwes, 2006). By contrast, in Experiment 2 of the current study, participants were asked to memorize the identity of face cues, and while color formed part of this object it did not require active memorization itself. This therefore suggests that all features related to the maintained object were able to guide attention. That said, results in Experiment 2 could be a reflection of the type of stimuli that were maintained in visual working memory (i.e., faces resulting in holistic object processing; Farah, Wilson, Drain, & Tanaka, 1998), or due to temporal variations from the relatively short inter-stimulus interval used in the current study versus other studies (e.g., Olivers et al., 2006). Clarifying these possible factors in future research would elucidate how maintained object representations in visual working memory impact the guidance of attention during search.

Finally, it is possible that findings in the current study may not reflect a role of visual working memory, but rather of 'selection history' (e.g., Awh et al., 2012). This account proposes that attention can be rapidly biased by previous experience and search history, producing for example a strong bias towards red objects if 'red' has been recently selected in a previous object and so primed for future selection. This account could explain why anxiety was associated with an increased bias to colors associated with threatening stimuli in Experiment 1, if assuming that anxious individuals were unable to prevent selection of task-irrelevant angry face cues. It can moreover accommodate findings in Experiment 2, as participants were encouraged to attend to all face cues and subsequent color biases were observed for all conditions irrespective of individual differences in trait anxiety. A key challenge for future research will be to dissociate this selection history model from a visual working memory account, which would provide insight particularly in relation to the role of anxiety in selective attention to threat. Indeed, it is possible that associative biases in attention seen in anxious individuals following attentional capture by threat might reflect a combination of both task-irrelevant visual working memory representation of threatening objects and biases due to selection history.

In summary, the current study demonstrates that trait anxiety is associated with rapidly-formed biases in attention towards task-irrelevant threat-associated visual features. This phenomenon, however, is not unique to threat or anxiety per se, and can seemingly also occur for relevant objects in the environment that are actively attended and encoded into visual working memory, regardless of their threat value and regardless of personality factors. This suggests that anxious individuals may be prone to not only attend to task-irrelevant threat but also deeply encode such objects to the level of visual working memory, giving rise to associative biases in feature-based attention. These findings imply that other observed phenomena in selective attention related to anxiety, such as delayed disengagement of spatial attention from threat, may also stem from task-irrelevant visual working memory encoding.

Acknowledgements

This work was supported by grant ES/R003459/1 awarded to the author from the Economic and Social Research Council (ESRC), United Kingdom. I thank Martin Eimer for comments on a previous version of this manuscript, and Merve Bayrak for data collection assistance in a pilot study relating to this work. Data and materials from this study are available upon request to the author.

References

Algom, D., Chajut, E., & Lev, S. (2004). A rational look at the emotional stroop phenomenon: A generic slowdown, not a stroop effect. *Journal of Experimental Psychology: General*, *133*, 323-338.

Awh, E., Belopolsky, A.V., & Theeuwes, J. (2012). Top-down versus bottom-up attentional control: A failed theoretical dichotomy. *Trends in Cognitive Sciences*, *16*, 437-443.

Bar-Haim, Y., Lamy, D., Pergamin, L., Bakermans-Kranenburg, M.J., & van IJzendoorn, M.H. (2007). Threat-related attentional bias in anxious and nonanxious individuals: A meta-analytic study. *Psychological Bulletin*, *133*, 1-24.

Berggren, N., & Derakshan, N. (2013). Blinded by fear? Prior exposure to fearful faces enhances attentional processing of task-irrelevant stimuli. *Quarterly Journal of Experimental Psychology*, *66*, 2204-2218.

Berggren, N., & Eimer, M. (2018). Visual working memory load disrupts template-guided attentional selection during visual search. *Journal of Cognitive Neuroscience*, *30*, 1902-1915.

Berggren, N., Jenkins, M., McCants, C.W., & Eimer, M. (2017). The spatially global control of attentional target selection in visual search. *Visual Cognition*, *25*, 196-214.

Carlisle, N.B., Arita, J.T., Pardo, D., & Woodman, G.F. (2011). Attentional templates in visual working memory. *Journal of Neuroscience*, *31*, 9315-9322.

Cisler, J.M., Bacon, A.K., & Williams, N.L. (2009). Phenomenological characteristics of attentional biases towards threat: A critical review. *Cognitive Therapy and Research*, *33*, 221-234.

De Houwer, J., Thomas, S., & Baeyens, F. (2001). Associative learning of likes and dislikes: A review of 25 years of research on human evaluative conditioning. *Psychological Bulletin*, *127*, 853-869.

Duncan, J., & Humphreys, G. (1992). Beyond the search surface: Visual search and attentional engagement. *Journal of Experimental Psychology: Human Perception and Performance*, *18*, 578-588.

Easterbrook, J.A. (1959). The effect of emotion on cue utilization and the organization of behavior. *Psychological Review*, *66*, 183-201.

Ekman, P., & Friesen, W.V. (1976). *Pictures of facial affect*. Palo Alto, CA: Consulting Psychologists Press.

Eysenck, M.W. (1992). *Anxiety: The cognitive perspective.* Hove, England: Erlbaum.

Eysenck, M.W., Derakshan, N., Santos, R., & Calvo, M.G. (2007). Anxiety and cognitive performance: Attentional control theory. *Emotion*, *7*, 336-353.

Farah, M.J., Wilson, K.D., Drain, M., & Tanaka, J.N. (1998). What is “special” about face perception? *Psychological Review*, *105*, 482-498.

Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using

G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods*, *41*, 1149-1160.

Ferneyhough, E., Kim, M.K., Phelps, E.A., & Carrasco, M. (2013). Anxiety modulates the effects of emotion and attention on early vision. *Cognition & Emotion*, *27*, 166-176.

Folk, C.L., Leber, A.B., & Egeth, H.E. (2002). Made you blink! Contingent attentional capture produces a spatial blink. *Perception & Psychophysics*, *64*, 741-753.

Folk, C.L., Remington, R.W., & Johnston, J.C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance*, *18*, 1030-1044.

Fox, E. (1994). Attentional bias in anxiety: A defective inhibition hypothesis. *Cognition and Emotion*, *8*, 165-195.

Fox, E., Russo, R., & Dutton, K. (2002). Attentional bias for threat: Evidence for delayed disengagement from emotional faces. *Cognition & Emotion*, *16*, 355-379.

Franconeri, S.L., Alvarez, G.A., & Cavanagh, P. (2013). Flexible cognitive resources: Competitive content maps for attention and memory. *Trends in Cognitive Sciences*, *17*, 134-141.

Gayet, S., Stein, T., & Peelen, M. (in press). The danger of interpreting detection differences between image categories. *PsyArXiv*.

Gomes, N., Soares, S.C., Silva, S., & Silva, C.F. (2018). Mind the snake: Fear detection relies on low spatial frequencies. *Emotion*, *18*, 886-895.

Koster, E.H.W, Crombez, G., Verschuere, B., Van Damme, S., & Wiersema, J.R. (2006). Components of attentional bias to threat in high trait anxiety: Facilitated engagement, impaired disengagement, and attentional avoidance. *Behaviour Research and Therapy*, *44*, 1757-1771.

Leonard, C.J., Balestreri, A., & Luck, S.J. (2015). Interactions between space-based and feature-based attention. *Journal of Experimental Psychology: Human Perception and Performance*, *41*, 11-16.

Londsdorf, T.B., Menz, M.M., Andretta, M., Fullana, M.A., Golkar, A., Haaker, J., et al. (2017). Don't fear 'fear conditioning': Methodological considerations for the design and analysis of studies on human fear acquisition, extinction, and return of fear. *Neuroscience and Biobehavioral Reviews*, *77*, 247-285.

Martinez-Trujillo, J.C., & Treue, S. (2004). Feature-based attention increases the selectivity of population responses in primate visual cortex. *Current Biology*, *14*, 744-751.

Matthews, G., & Wells, A. (2000). Attention, automaticity, and affective disorder. *Behavior Modification*, *24*, 69-93.

Mogg, K., & Bradley, B.P. (1998). A cognitive-motivational analysis of anxiety. *Behaviour Research and Therapy*, *36*, 809-848.

Notebaert, L., Crombez, G., Van Damme, S., De Houwer, J., & Theeuwes, J. (2010). Looking out for danger: An attentional bias towards spatially predictable threatening stimuli. *Behaviour Research and Therapy*, *48*, 1150-1154.

Notebaert, L., Crombez, G., Van Damme, S., De Houwer, J., & Theeuwes, J. (2011). Signals of threat do not capture, but prioritize, attention: A conditioning approach. *Emotion*, *11*, 81-89.

Notebaert, L., Crombez, G., Van Damme, S., Durnez, W., & Theeuwes, J. (2013). Attentional prioritization of threatening information: Examining the role of the size of the attentional window. *Cognition & Emotion*, *27*, 621-631.

Ohman, A., Flykt, A., & Esteves, F. (2001). Emotion drives attention: Detecting the snake in the grass. *Journal of Experimental Psychology: General*, *130*, 466-478.

Olivers, C.N.L., Meijer, F., & Theeuwes, J. (2006). Feature-based memory-driven attentional capture: Visual working memory content affects visual attention. *Journal of Experimental Psychology: Human Perception and Performance*, *32*, 1243-1265.

Rudaizky, D., Basanovic, J., & MacLeod, C. (2014). Biased attentional engagement with, and disengagement from, negative information: Independent cognitive pathways to anxiety vulnerability. *Cognition & Emotion*, *28*, 245-259.

Serences, J.T., & Boynton, G.M. (2007). Feature-based attentional modulations in the absence of direct visual stimulation. *Neuron*, *55*, 301-312.

Sheppes, G., Luria, R., Fukudua, K., & Gross, J.J. (2013). There’s more to anxiety than meets the eye: Isolating threat-related attentional engagement and disengagement biases. *Emotion*, *13*, 520-528.

Soto, D., Heinke, D., Humphreys, G.W., & Blanco, M.J. (2005). Early, involuntary top-down guidance of attention from working memory. *Journal of Experimental Psychology: Human Perception and Performance*, *31*, 248-261.

Soto, D., Hodsoll, J., Rotshtein, P., & Humphreys, G.W. (2008). Automatic guidance of attention from working memory. *Trends in Cognitive Sciences*, *12*, 342-348.

Spielberger, C.D., Gorsuch, R.L., Lushene, R., Vagg, P.R., & Jacobs, G.A. (1983). *Manual for the State-Trait Anxiety Inventory*. Palo Alto, CA: Consulting Psychologists Press.

Stout, D.M., Shackman, A.J., & Larson, C.L. (2013). Failure to filter: Anxious individuals show inefficient gating of threat from working memory. *Frontiers in Human Neuroscience*, *7*, 58.

Stout, D.M., Shackman, A.J., Pedersen, W.S., Miskovich, T.A., & Larson, C.L. (2017). Neural circuitry governing anxious individuals' mis-allocation of working memory to threat. *Scientific Reports*, *7*, 8742.

Tottenham, N., Tanaka, J.W., Leon, A.C., McCarry, T., Nurse, M., Hare, T.A., et al. (2009). The NimStim set of facial expressions: Judgments from untrained research participants. *Psychiatry Research*, *168*, 242-249.

Wells, A., & Matthews, G. (1994). *Attention and emotion: A clinical perspective*. Hillsdale, NJ:

Lawrence Erlbaum Associates.

Wilkowski, B.M., & Robinson, M.D. (2006). Stopping dead in one's tracks: Motor inhibition following incidental evaluations. *Journal of Experimental Social Psychology*, *42*, 479-490.

Williams, J.M.G., Mathews, A., & MacLeod, C. (1996). The emotional Stroop task and psychopathology. *Psychological Bulletin*, *120*, 3-24.

Williams, J.M.G., Watts, F.N., MacLeod, C., & Mathews, A. (1988). *Cognitive psychology and emotional disorders.* Chichester: Wiley.

Wolfe, J.M. (2007). Guided search 4.0: Current progress with a model of visual search. In W. Gray (Ed.), *Integrated models of cognitive systems* (pp. 99-120). New York, NY: Oxford.

Woodman, G.F., Luck, S.J., & Schall, J.D. (2007). The role of working memory representations in the control of attention. *Cerebral Cortex*, *17*(Suppl 1), i118-i124.

Table 1: Mean reaction time in milliseconds (upper row) and percentage error rate (lower row) data as a function of Emotion and Color Validity in Experiment 1. Standard deviations are presented in parentheses.

	Color Presence	
Face Expression	Present	Absent
Neutral	774 (105)	778 (98)
	11 (9)	13 (9)
Happy	775 (96)	771 (101)
	12 (8)	12 (8)
Angry	787 (107)	773 (100)
	12 (9)	12 (8)

Table 2: Mean reaction time in milliseconds (upper row) and percentage error rate (lower row) data as a function of Emotion and Color Validity in Experiment 2. Standard deviations are presented in parentheses.

	Color Presence	
Face Expression	Present	Absent
Neutral	810 (100)	803 (101)
	10 (7)	10 (8)
Angry	810 (106)	794 (103)
	10 (7)	10 (8)

Figure captions

Figure 1: Example experimental trial used in Experiment 1 (not to scale). Participants initially viewed a pair of identical face stimuli presented either side of fixation. These faces displayed either neutral, happy, or angry expressions, and were filtered to appear in different possible colors. In Experiment 1, participants were instructed to ignore these faces, and subsequently respond to visual search displays. Here, four square objects were presented around fixation, each containing a small gap in one of their sides. The target was defined as the object with a gap in its top or bottom side, with participants responding to which target orientation was present. Importantly, all square objects were presented in different colors. On color-present trials (as shown here), one of the non-target squares matched the color of the initial face cue. On color-absent trials, the color of the initial face cue did not appear as an object color in search displays. In Experiment 2, face cues were now designated task-relevant: participants were asked to memorize the identity of the face shown. On two-thirds of trials, a visual search display was subsequently shown, and participants responded to this as in Experiment 1 and could discard memorizing the face cue. On the other one-third of trials, search displays were replaced by a memory probe display containing two grayscale faces, with participants judging whether this face image matched or mismatched the preceding cue face’s identity.

Figure 2: Scatterplot demonstrating the positive correlation between self-reported trait anxiety score and color presence costs (i.e., color-present RT minus color-absent RT) following an angry face cue in Experiment 1.

Figure 1

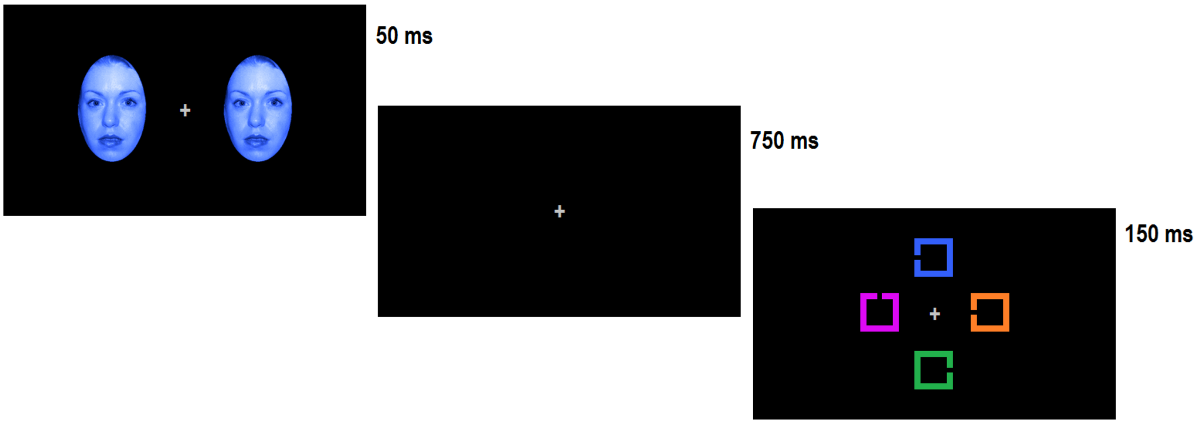
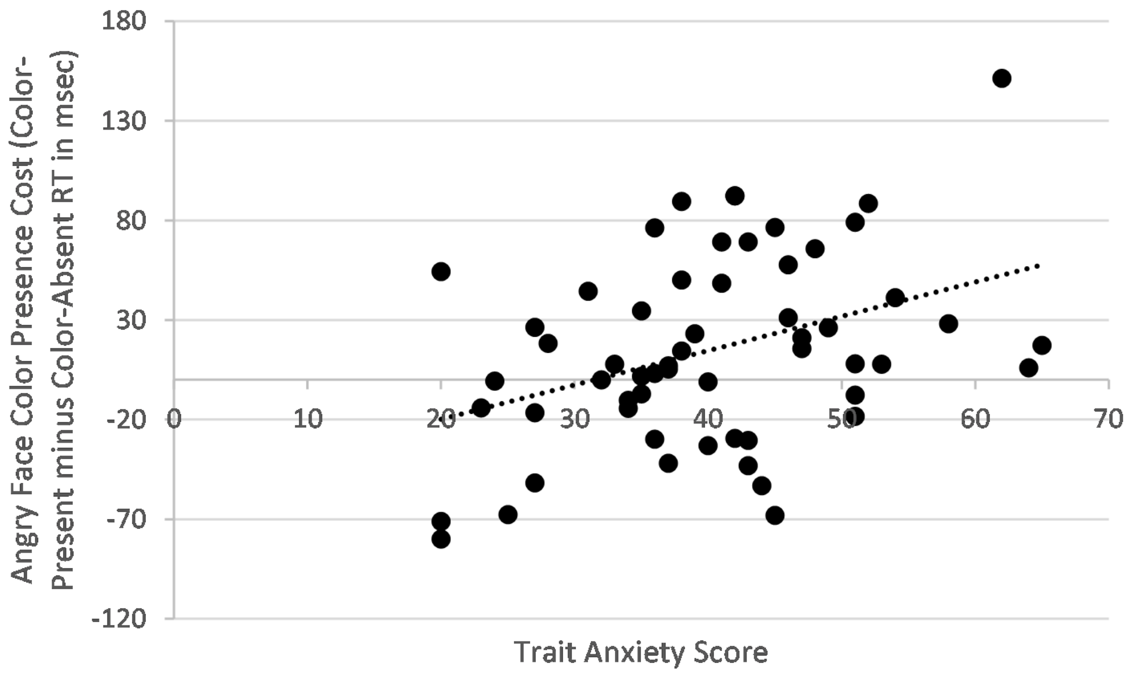


Figure 2


180
130
80
30
-20
-70
-120
0
10
20
30
40
50
60
70
Angry Face Color Presence Cost (Color-Present minus Color-Absent RT in msec)
Trait Anxiety Score