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# Emotional Faces, Visuo-Spatial Working Memory and Anxiety

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## Abstract

Recent research has demonstrated competition for limited cognitive resources, via emotional prioritization, occurs not only during attentional capture, but also extends to visuo-spatial working memory (VSWM). However, to what extent VSWM biases are influenced by individual differences such as anxiety has received limited attention. Here, we investigated this using a novel change detection paradigm with memory arrays containing 3, 4 or 5 emotional faces (angry, happy and neutral) and participants (n = 41), preselected to be high or low trait anxious. The task of participants was to detect if a probe face, presented in the location of one of the original memory array faces, was the 'same' or 'different'. On 'no change' trials results revealed that high anxious participants demonstrated poorer performance for larger set sizes than low anxious participants per se. Additionally, high anxious participants demonstrated a threat bias, whereas low anxious participants trended toward emotion superiority. On 'change' trials, change detection altered as a function of expression change; change detection was typically greatest when either the memory or probe face was angry. Results reveal VSWM capacity is modulated by trait anxiety and stimulus threat value, as well as highlight the importance of actively investigating (or controlling for) individual differences.

***Keywords:*** *Emotional Faces; Visuo-Spatial; Anxiety*

## Introduction

Literature suggests that stimuli of an emotive nature, especially those indicating potential threat, are more effective in their capture of attention than non-emotive stimuli [1,2]. This is consistent with models of fear and threat processing, in which specialised (neural/dynamic) mechanisms responsible for the enhanced processing of threat-related information are proposed [3-5]. In such models it is argued that attentional resources are preferentially allocated to threat-related cues, relative to other types of non-emotional information, given the ability to process such information efficiently poses several survival advantages. Consistent with this, much behavioural data utilizing Stroop, visual search, visual probe and rapid serial visual presentation (RSVP) reliably demonstrates that when there is competition for cognitive resources, threatening information is prioritized [6-8].

Simione., *et al.* [9] have demonstrated competition for limited cognitive resources and, emotional prioritization, extends to visual-spatial working (short-term) memory. Using a novel probe report task, they demonstrated encoding superiority effects for both angry and happy, over neutral, faces. That is, when presented with an array of stimuli displaying schematic angry, neutral and happy faces, participants were more likely to remember the locations of where the happy and angry faces had been presented as compared to the neutral faces. However, Simione., *et al.* further revealed that recall of facial emotional expression altered as a function of set-size and presentation duration. That is, they found emotion superiority when the task was of limited cognitive load (i.e. small to-be-remembered set-size with long array exposure duration), but threat superiority when competition for resources was maximal (i.e. large set-size with brief array exposure). In accounting for results and based upon influential theories of visual attention [10,11] they suggest the potential significance of threatening/emotional stimuli results in such stimuli receiving a greater attentional weighting than other competing stimuli. This greater weighting allows for selective processing of emotional stimuli (and especially that which is threatening), over and above neutral stimuli, i.e. amplification of emotional stimuli and attenuation of neutral stimuli, respectively.

In the anxiety literature, greater attentional priority of threat is also observed to occur for those with high anxiety levels. In a number of prominent models of anxiety [12], it is proposed that threat detection processes are activated too rapidly or too easily in those with higher (trait) anxiety. Thus, high anxious individuals have a lowered threshold in terms of what stimuli in the environment capture their attention. This leads to the observation of facilitated engagement (and/or delayed disengagement) for certain stimuli; i.e. the rapid detection (and/or increased viewing time), of stimuli that are mildly threatening or ambiguous in nature [13].

In accord with this, several studies demonstrate that high anxious (HA), as compared to low anxious (LA), individuals respond more quickly to information appearing in the location of mildly threatening stimuli, or prioritise processing of threat-related stimuli [14]. Using RSVP, Fox, Russo and Georgiou [15] demonstrated that whilst both HA and LA individuals demonstrate an attentional blink (AB) for emotional faces, for those reporting high anxiety, the magnitude of the AB was significantly reduced for fearful expressions. Similar results have been observed by Kelly, Maratos, Lipka and Croker [16] in a child population. Using schematic angry, happy and neutral expressions, they found an emotion-superiority effect for LA children, but a threat-superiority effect for HA children. Thus, whereas LA children demonstrated a reduced AB for both happy and angry faces, HA children demonstrated a reduced AB for angry as compared to neutral and happy faces. Such studies evidence that HA populations demonstrate a greater processing bias for mildly threatening stimuli as compared to their LA counterparts.

Considering this and given that Simione., *et al*. [9] have found effects of emotional processing bias to extend to working memory, it is plausible that anxiety also influences visual-spatial working memory (VSWM) processes. That is, an interaction effect can be hypothesised whereby HA individuals will show heightened retention of the location of mildly threatening stimuli (above and beyond all further emotional/neutral stimuli), whilst LA individuals would show VSWM emotion superiority effects per se. This would additionally fit with the theorised role of the amygdala in: orienting/arousal to salient stimuli [3], threat-processing biases [4] and anxiety [17,18]. Interestingly, Berggren, Curtis and Derakshan [19] have recently demonstrated task irrelevant emotional stimuli to interfere with a non-emotional VSWM task in HA, but not LA, participants when the task was attentionally demanding. However, as higher anxiety has been implicated with poorer working memory capacity per se [20] and this effect has recently been found to be independent of emotion, one might further expect anxiety to impact upon VSWM performance more generally. For example, Balderston., *et al*. [21], found that patients with anxiety were impaired relative to controls on an N-back task, regardless of the anticipation of threat (i.e. electric shock or otherwise) and, irrespective of task difficulty/attentional load.

Therefore, to explore the effects of anxiety on VSWM processing and specifically, task-relevant emotional faces, we used a modified version of the Simione., *et al*. [9] VSWM paradigm, based on change detection rather than report. We investigated competition between faces of different emotional categories for storage in VSWM as a function of anxiety status (HA vs. LA), expression (angry, happy, neutral) and set-size (3, 4, 5 to-be-remembered faces). We utilised a change detection- rather than report- paradigm to assess VSWM given: i) arguments of reliability and ii) that such a paradigm allows for the novel investigation of the effects of change in emotional face expression between the memory array and test probe. We hypothesised two interaction effects: firstly that HA participants, as compared to LA participants, would demonstrate poorer performance when the task was of increased difficulty (i.e. attentional/cognitive load) and, secondly, that HA individuals would demonstrate better performance for trials in which an angry face was task-relevant, whereas LA individuals would demonstrate emotion superiority per se.

## Methods

### Design

We employed a mixed measures design, with 'anxiety' (HA vs. LA) as the between subjects variable and target expression (angry, happy, neutral)/set-size (3, 4, 5) as the within-subjects variables. Assuming a medium effect size (0.25), to achieve acceptable power (i.e. 0.8; with alpha set at 0.05) for our main hypothesis of interest i.e. a target expression-anxiety interaction, the calculated sample size was 28 (i.e. 14 HA vs. 14 LA individuals).

### Participants

In a pre-selection process, 140 staff and students from a UK University completed the Spielberger Trait Anxiety Inventory [22]. Those who scored > 50 or < 35 were invited to participate in the full study. Subsequently, 41 participants responded (34 females; mean age = 33.84 years, SD = 13.73 years) and took part in the full experiment. These were 19 HA and 22 LA participants. All participants reported normal or corrected-to-normal vision. Further details are provided in the data screening section.

Ethical approval was received from the Psychology Research Ethics Committee, University of Derby, for both phases and all participants provided written informed consent. Importantly, this ethics committee adheres to guidance provided by the British Psychological Society (i.e. Code of Ethics and Conduct).

### Stimuli

We used the same schematic faces as Simione., *et al*. [9, see also 26]. These included an angry (A), happy (H) and neutral (N) face. Each differed with respect to three main features: eyebrow, eye and mouth shape (Figure 1A upper panel). Adapting their VSWM task, stimuli were presented in one of eight possible locations around the centre of a flat screen monitor. Each stimulus subtended a region of approximately 2° x 2.2°, presented at a distance of 5° ± 0.5° from the centre, resulting in an average distance between any two stimuli of 3.8°. A small central fixation cross was presented throughout each trial. Stimulus presentation was controlled by E-prime software.

### Procedure

Each trial started with the presentation of the central fixation, which participants were instructed to fixate throughout the trial. After 1000ms the memory array was presented. This consisted of three, four or five schematic target faces, placed randomly in one of the eight possible locations surrounding the central fixation. The memory array was presented for 150ms, followed by a 1000ms retention interval. After which, a probe 'test' face was presented at one of the same locations: in half of trials, the face presented had the same expression as in the memory array, whereas in the further half it had a different expression randomly picked from the remaining two. The task of the participant was to report if the expression of the face appearing after the retention interval was the 'same' or 'different', by pressing corresponding keyboard digits (counterbalanced across participants). After a response was recorded, a blank screen was presented for 1000ms, before a new trial keys was initiated. Trial events are depicted in figure 1A (lower panel).

Prior to the experiment proper, participants completed 36 practice trials; four for each of the nine combinations of target face emotional expression (Angry, Happy, Neutral) and set-size (3, 4, 5). Following verification of task understanding, each participant completed the 360 experimental trials. These consisted of 40 trials for each of the nine combinations of target face emotional expression and set-size, divided into four blocks of 90 trials separated by a short rest interval. The trial sequence for the different conditions was fully randomized within blocks. The dependent variable was correct report of the probe stimulus (Angry, Happy, or Neutral in percentage accuracy).

The experiment was administered individually to each participant in a quiet, dark room and lasted approximately 50 minutes.

### Data screening

Four participant's datasets were removed due to poor task accuracy (i.e., performed no better than chance level). This resulted in a final sample of 16 HA (14 females; mean age = 30.05 years; mean STAI-T score = 59) and 21 LA (17 females; mean age = 36.82 years; mean STAI-T score = 31) participants. The two groups did not differ statistically by age nor gender although, as expected, an independent measures t-test demonstrated the HA group to have significantly higher trait anxiety scores, $t (36) = -13.175$, $p < .001$.

Trials in which reaction time was less than 200ms or greater than 5000ms were removed, resulting in a loss of 1.4% of the data.

## Results

To allow comprehensive analysis, we analysed trials in which the target and probe face remained the same ('no change' trials) separately to those where they changed ('change' trials). This strategy was employed given participants performed significantly better on trials in which the expression changed (average accuracy = 65.93%) compared with trials where the expression remained the same (average accuracy = 57.02%), $t = 2.81$, $p < .01$. For each trial type (i.e. same; no change), we conducted a mixed-measures ANOVA with group (high anxiety, low anxiety), target expression (angry, happy, neutral) and set-size (3, 4, 5) as the IV's and change detection accuracy (in percentage) as the DV. Where applicable we performed planned comparisons and post-hoc comparisons based upon our apriori hypotheses.

## 'No change' trial performance

The 2 x 3 x 3 mixed-ANOVA of change detection accuracy (57.02%) with group as the between-subjects factor and set-size/emotional expression as the within-subjects factors revealed no main effect of group, but significant main effects of both set-size, $F (2,70) = 18.23$, $p < .01$, $\eta_p^2 = .34$ and target emotional expression, $F(2,70) = 6.56$, $p < .01$, $\eta_p^2 = .0.16$. We further found a significant interaction between group and set-size, $F (2,70) = 3.325$, $p < .05$, $\eta_p^2 = .09$.

For the main effect of target expression, pair-wise comparisons revealed more accurate performance for no-change angry expressions ($M = 61.23$) than for either happy ($M = 57.59$), $p < .05$, or neutral expressions ($M = 52.25$), $p < 0.01$, and more accurate performance for no change happy expressions than for neutral expressions, $p < .01$. For the main effect of set-size, pair-wise comparisons revealed that performance declined significantly when set-size increased from three to four ($M_{ss3} = 61.52$, $M_{ss4} = 56.63$, $p < 0.01$) and from four to five stimuli ($M_{ss4} = 56.63$, $M_{ss5} = 52.91$, $p < 0.05$). However, this effect was qualified by a group by set-size interaction (Figure 1B). To clarify this interaction, a one-way Bonferroni-corrected ANOVA on percentage accuracy with set-size as the independent factor for each participant group (i.e. HA participants; LA participants) was performed. For the HA group a significant main effect of set-size, $F (2,30) = 11.54$, $p < .001$, $\eta_p^2 = .43$, was observed. Bonferroni-corrected pairwise comparisons revealed that for the HA group, performance accuracy significantly decreased from set-size three ($M = 62.96$) to four ($M = 54.2$), $p < 0.001$, but not from set-size four to five ($M = 53.91$), $p = 0.89$. For the LA group a significant main effect of set-size was again observed, $F (2,40) = 10.16$, $p < .001$, $\eta_p^2 = .34$. Here, pairwise comparisons revealed that performance accuracy did not differ between set-size three ($M = 60.41$) and four ($M = 58.49$), $p = 0.32$, but did significantly decrease from set-size four to five ($M = 52.15$), $p < .01$.

Whilst we found no significant interactions between group and target, $p = .55$, to specifically test our a priori hypotheses that high anxious individuals would demonstrate threat superiority, whilst low anxious individuals would demonstrate emotion superiority, we conducted a one-way ANOVA on percentage accuracy with target expression as the IV for each anxiety group separately (Figure 1C). For the HA group, we found a significant main effect of target expression, $F (2,30) = 4.67$, $p < .05$, $\eta_p^2 = .24$. Pairwise comparisons revealed significantly better performance on angry target trials ($M = 63.04$) as compared to both happy ($M = 56.55$), $p < .05$ and neutral ($M = 51.48$), $p < .01$, target trials, while performances for happy and neutral trials were comparable, $p = .24$. For the LA group, only a trend toward significance was found for the main effect of target type, $F (2,40) = 2.5$, $p = .09$, $\eta_p^2 = .11$. In fact, pairwise comparisons revealed that performance on angry trials (M = 59.85) did not differ from that on happy trials (M = 58.39), p = 0.99 and that performance on neutral trials (M = 52.84) was significantly worse as compared to angry, p < .05, but not happy trials, p = .08.

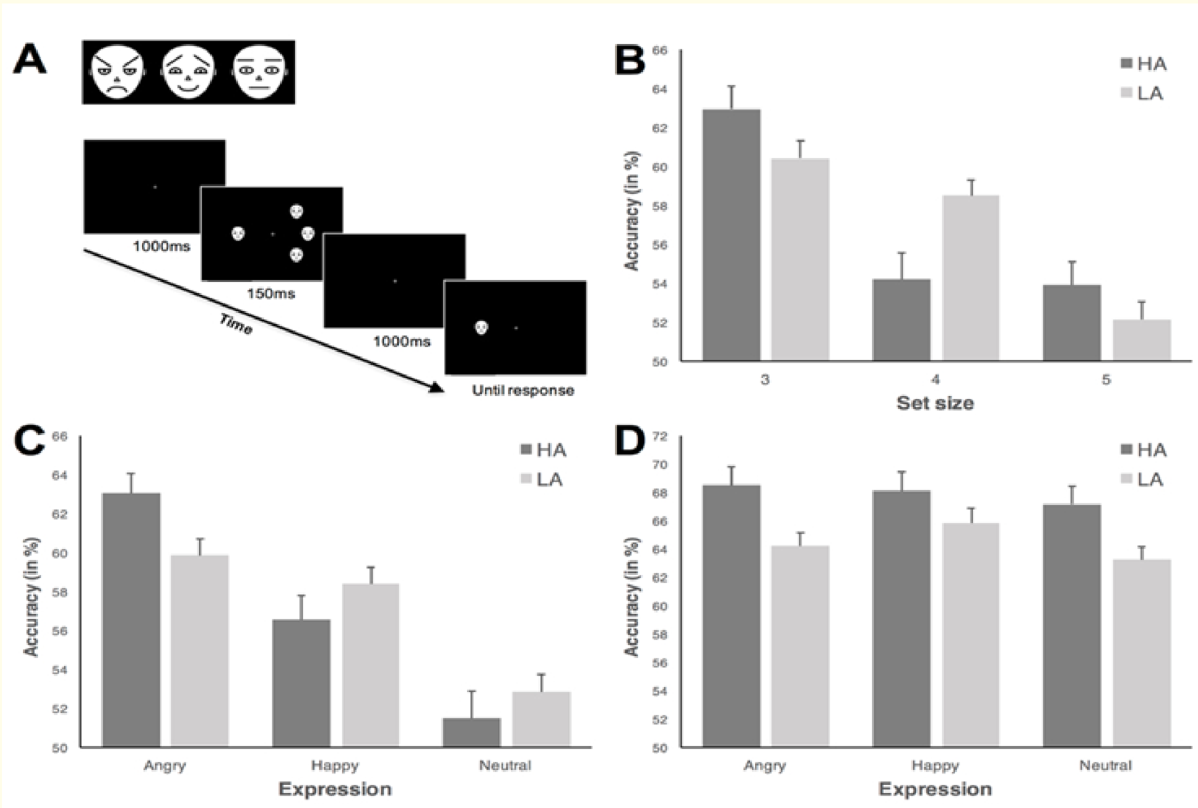


***Figure 1:*** *A (upper): The three schematic faces included in the experiment. A (lower): An example of the experimental procedure. In this trial, the target face has an angry expression and the probe has the same emotional expression after the retention interval (i.e. no change trial). B. Mean percentage accuracies scored by the high-anxiety and low-anxiety group in the 'no change' trials for the three set sizes. C. Mean percentage accuracies scored by the high-anxiety and low-anxiety group in the 'no change' trials for the three emotional expressions of target face. D. Mean percentage accuracies scored by the high-anxiety and low-anxiety group in the 'change' trials for the three emotional expressions of target face. In all cases, error bars represent standard error of the mean.*

### 'Change' trial performance

A 2 x 3 x 3 mixed measures ANOVA of percentage change detection accuracy (65.93%) with group as the between-subjects factor and set-size/target expression as the within-subjects factors revealed no significant main effects, all ps > .2, nor any significant interactions, all ps > .64. For comparison with 'no change' trials (See figure 1D).

To explore 'change' trials further, we investigated 'change detection' as a function of probe expression (See table 1). Here, we ran three separate 'target expression' analyses (i.e. angry, happy and neutral) with group (high anxiety, low anxiety) as the between-subjects factor and set-size (3, 4, 5) and probe expression (i.e. angry and happy for the neutral face; happy and neutral for the angry face; angry and neutral for the happy face) as the within-subjects factors.

| Target expression | Probe expression | Group HA | | Group LA | |
|---|---|---|---|---|---|
| Neutral | Angry | 69.63 | (1.31) | 68.61 | (0.99) |
| | Happy | 64.71 | (1.22) | 57.83 | (0.79) |
| Angry | Happy | 63.16 | (1.21) | 57.53 | (0.96) |
| | Neutral | 73.79 | (1.37) | 70.88 | (0.81) |
| Happy | Angry | 65.39 | (1.30) | 63.73 | (1.06) |
| | Neutral | 70.81 | (1.37) | 67.96 | (0.98) |

***Table 1:*** *Accuracies reported in relation to the probe (i.e. new) emotional expression.*

For neutral target trials, we found a significant effect of probe expression only, $F(1,35) = 13.87$, $p < .01$, $\eta_p^2 = .28$. Here, performance (i.e. change detection) was greater when the probe expression was angry (M = 69.05) compared with when it was happy (M = 60.8), $p < .01$. Thus participants were more likely to detect a neutral expression changing to an angry expression, than a neutral expression changing to a happy expression.

For angry target trials, we again found a significant effect of probe expression only, $F(1,35) = 34.1$, $p < .001$, $\eta_p^2 = .49$. Here, change detection was greater when the probe expression was neutral (M = 72.14) compared with when it was happy (M = 59.97), $p < .01$. Thus, participants were more likely to detect an angry expression changing to a neutral expression as compared to an angry expression changing to a happy expression.

Finally, for happy target trials, no significant main effects nor significant interactions were found.

## Discussion

The primary purpose of the present investigation was to explore the effects of anxiety on VSWM retention as a function of emotional expression consistency and attentional (or cognitive) load. To enable this, we used a novel memory array paradigm that allowed investigation of trials in which the target and probe face remained the same (no change trials), as well as trials in which the target and probe face differed (change trials). A number of results were returned. Firstly, considering 'no change' trials, we found anxiety affected both working memory capacity per se and recall as a function of target expression. To expand, the HA group demonstrated reduced target accuracy for trials in which the memory array contained four or five stimuli (as compared to three), whereas the LA group demonstrated reduced target accuracy only when the memory array contained 5 stimuli. Additionally, whilst a main effect of target type was observed, planned comparisons revealed this reflected a threat superiority effect for the HA group and an emotion superiority trend for the LA group. For 'change' trials, however, we found no difference in target accuracy (i.e. the report of 'different') as a function of memory array size, anxiety or target expression; although we did observe differences as a function of expression change. That is, all participants were significantly more likely to detect that the target face had changed, if it changed from: i) a neutral to an angry face, as compared to a happy face; and ii) an angry to a neutral face, as compared to a happy face. Importantly, when a happy face changed to either an angry or neutral face, no differences in change detection accuracy were revealed. Results will be discussed in turn.

Consistent with Moran [20], we found a working memory deficit for HA as compared to LA individuals on no change trials when cognitive load was increased. That is, we observed a working memory deficit for HA individuals for set sizes of both 4 and 5 to-be-remembered stimuli as compared to 3, whereas for LA participants a similar performance decrement was only observed for stimulus set sizes of 5. This suggests that HA participants failed to maintain relevant visuo-spatial information in working memory during the retention period for the more attentionally demanding versions of the task. One explanation for this finding proposed by Moran [20] is that physiological arousal as a function of trait anxiety and spatial working memory compete for prefrontal cortex (PFC) and posterior-parietal cortex in demanding situations. Thus anxious arousal interferes with the recruitment and/or maintenance of spatial information in PFC and hence working memory difficulties [21].

Further exploration of performance on no change trials, however, revealed differential effects of target expression as a function of anxiety. That is, whilst accuracy was greatest on trials where the target/probe face was angry, compared with either happy or neutral, planned comparisons revealed a threat superiority effect for HA individuals, but an emotion superiority trend for LA individuals. This suggests that high anxious individuals demonstrated prioritisation of the location of the angry face stimuli over both happy and neutral face stimuli. Simione., *et al*. [9] have proposed threatening face representations are enhanced by an attentional weighting mechanism, which allows for their prioritised selection and storage in VSWM. They note that the amygdala could serve as one key structure in this process given its observed roles in both threat processing [28] and orienting/arousal [3]. Importantly, as heightened amygdala activity (and the salience network more generally), is implicated in anxiety [18] and threatening face processing within anxious populations [17], for HA individuals this would result in amplification of threat stimuli (i.e. an angry face) for storage in VSWM as compared to all other stimuli. In other words, a VSWM threat superiority effect for mildly threatening stimuli, as was found.

Of course, such an effect could equally explain the poorer performance observed on both happy and neutral no change trials for the HA individuals. That is, prioritised processing of mild threat as a consequence of trait anxiety could interfere with attention to, and encoding of, non-threatening stimuli. Here, on trials where the target face was either neutral or happy, inappropriate encoding strategies of the original memory array could have ensued due to the presence of an angry face in this array prioritising attentional capture in the HA participants. This would lead to encoding and storage attenuation of the location of non-threat faces (i.e. happy and/or neutral faces) and, subsequently, poorer performance on no change happy and neutral trials. This is somewhat consistent with the research of Berggren., *et al*. [19] who found filtering efficiency was disrupted by the presence of a non-task relevant fearful face in their state anxious participants only. In LA individuals such heightened threat biases are not observed for mildly threatening stimuli, nor potentially the associated changes in dynamic brain networks [5], in which case encoding of all emotional stimuli predominates (i.e. emotion-superiority effects).

Turning to change trials, we found no overall difference in performance as a function of set-size, target expression or anxiety. Notably, however, performance on change trials was significantly better as compared to no change trials. Potentially, therefore, the task was of insufficient difficulty to introduce competition for encoding and storage in VSWM. A similar result was found by Simione., *et al*. [9]. Here, emotional superiority and then threat superiority, only emerged as task difficulty (i.e. attentional/cognitive load) increased. In the present study, it can be hypothesised that ‘change’ trials were easier to solve, as compared to no change trials, as the ‘change/no change’ decision could be solved on the basis of mismatching feature detection. On ‘no change’ trials, however, participants had to perform a full match of the stored face with the probe, which is a more demanding processing.

Analysis of change trial data as a function of probe face, however, did reveal interesting findings. Firstly, participants were more likely to detect a neutral face changing to an angry face, than a neutral face changing to a happy face. Here, given that both the angry and happy target faces were identical in terms of visual complexity/features, this accords with the hypothesis that attention is preferentially allocated to threat-related cues [4,6]. To expand, this suggests that threat information was prioritised and, subsequently, the encoding of a ‘new’ threat (where once there had been none) was observed. This threat prioritisation argument is further supported when one considers there was no difference in report accuracy when a happy face changed to either an angry or neutral face; yet the same was not true when an angry face changed to a neutral or happy face. In both cases, given the neutral face was the visually dissimilar stimulus, such a change should have been easier to report on the basis of feature detection alone. This was found when an angry face changed to either a neutral or happy face (where report of the neutral test face was greater), but not when the happy face changed to a neutral or angry face (where report of the neutral and angry probe faces was equivalent).

Change detection has been associated with a fronto-parietal network and the notion of a global workspace for conscious decisions [23]. It can be hypothesized that a threat-related attentional bias in matching memory and probe arrays, as in our study, involves the functional coupling of such a network with anterior insula and anterior cingulate cortex, two regions of the salience network [24]. These networks then interact with the amygdala and/or visual processing regions to provide an interface between cognitive control and emotional processing [25]; which could be further influenced by anxiety. However, to explore this further neuroimaging investigation utilising our paradigm would be necessary.

## Conclusion

To sum, the results of this study reveal anxiety modulates VSWM in terms of both capacity and prioritisation of stimuli for storage. Specifically, trait anxiety is associated with heightened prioritisation and storage of threatening faces. In using a novel probe detection paradigm, findings further demonstrate that change detection per se is influenced by the potential threat value of a stimulus. Lastly, the differential results observed in this research for high- compared with low- trait anxious participants would question whether the sometimes equivocal threat and/or emotional superiority effects observed in previous research reflect an absence to measure (or control for) individual differences such as (trait) anxiety. Indeed, as suggested as a direction of future research by Schweizer., *et al.* [27], the present study is one of the first to investigate the combined impact of affective salience and affective state upon working memory.

## Compliance with Ethical Standards

The authors declare that they have no conflict of interest. Of note the progression of this research was not part of an externally funded grant bid, nor was it linked to any financial or employment incentives.

Informed consent: Informed consent was obtained from all individual participants included in the study, in compliance with the British Psychological Society Code of Ethics and Conduct (latest version found at: https://www.bps.org.uk/news-and-policy/bps-code-ethics-and-conduct).

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