Nnadiebube Journal of Education in Africa (NJEA), Vol. 6, No 1, 2021

ATTENTIONAL BIAS FOR THREATENING FACIAL EXPRESSIONS: MANIPULATION OF STIMULUS SET SIZE

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Abstract

When multiple stimuli are presented simultaneously, they compete for limited attentional resources. This competition can be mediated by emotional valence, with angry faces eliciting faster and more accurate responses than neutral or positive faces in visual search and attentional blink studies. The current study was designed to investigate the consequences of this attentional bias on the accuracy of recognition memory for unfamiliar faces. In order to explore this issue, we used an inverse square root function based on the Sample-size model to characterise the relationship between N (set size) and d' (a signal detection theory measure) for threatening and non-threatening faces. The results revealed a decrease in recognition accuracy for neutral faces as the number of to-be-remembered (TBR) faces increased. When the target-face had an angry expression, however, d' was significantly greater than neutral faces but only when there are two faces in the display. This advantage appears to be largely independent of saccadic sampling and suggests the benefit occurred during maintenance rather than encoding. Importantly, when one of the distractors had an angry expression, sensitivity to neutral faces reduced dramatically. This suggests that angry faces exhaust the resources available to process neutral faces. Importantly, because set size increases the distribution of resources during encoding (indexed by reduction in fixations duration) and maintenance, the observed interaction between set size and threat superiority effect suggests that decreasing the quality of the perceptual information available by increasing set size, is likely to decrease threat superiority because it reduces the information driving the activation of the amygdala.

Keywords: Angry faces, visual attention, set size, visual working memory, eye movement.

In naturalistic environments, we often observe a face in the context of other faces. For example, a witness to a crime may observe one or more perpetrators, victims, and bystanders. Intuitively, memory for a given criminal perpetrator should be less complete when there are several persons in the visual field compared to only one, because the witness' attention is divided across several people. Indeed, the degree of attention the witness paid to the perpetrator has been put forth by the U.S. Supreme Court as a criterion for determining the likely accuracy of a witness' identification (ref). Yet, little research has examined how memory for a face is affected by the presence of other faces. What is more, even less is known about the cognitive processes that might underlie memory errors in these circumstances. These issues motivated the present study.

A handful of studies have investigated memory for single versus multiple persons in the context of eyewitness memory, and studies show consistently that memory is less accurate when there are multiple perpetrators as opposed to one perpetrator (Clifford &Hollin, 1981; Fahsing, Ask, &Granhag, 2004; Shepherd, 1983; Sporer, 1996; van Koppen&Lochum, 1997). Clifford and Hollin (1981), as an example, presented participants with a videotaped crime incident, varying between participants the number of perpetrators (one, three, or five). They then tested participants with a target present lineup, which contained the principle perpetrator. While participants in the one and three conditions identified the perpetrator at levels that exceeded chance expectation, identification accuracy did not exceed chance in the condition in which there were five perpetrators. As another example, in an archival study of armed bank robberies, witnesses' descriptions of robbers were less complete and less accurate when there were two perpetrators rather than one perpetrator (Fahsing, Ask, &Granhag, 2004). Findings from the eyewitness studies suggest that there are capacity limits in the number of faces that can be processed. However, it is difficult to draw theoretical inferences from these studies. One issue is that, in addition to perpetrator number, selective attention to the principle perpetrator might also vary across conditions. Consequently, memory for the principle perpetrator might be reduced across the single versus multiple perpetrator condition either because processing capacity has been exceeded, or because selective attention to the principle perpetrator is lower when he has accomplices. This potential confounding is not a fault of previous studies, but rather a consequence of the fact that they were geared towards maximising ecological rather than internal validity.

In the basic face processing literature, faces have been shown to automatically draw attention (ref), which might explain why memory for a given face is less accurate when another face is also present in the visual field. The biased competition model of visual attention (Desimone & Duncan, 1995; Shapiro & Miller, 2011) provides an account of object selection that is compatible with the Shared-resource model of visual working memory-VWM (Bays & Husain, 2008). According to this model, multiple stimuli falling within a single receptive-field (RF) compete for the encoding capacity of the neuron, such that the neuron's firing is ambiguous as to which stimulus is encoded (Chelazzi, Libera, Sani, &Santandrea, 2010). These competitive interactions mediate the allocation of VWM resources to different objects and operate alongside the stochastic processes that govern the precision and accuracy with which multiple objects are encoded and maintained. Competition between the to-be-remembered (TBR) objects can be biased via primarily bottom-up (stimulus-driven) or top-down (goal-driven) attentional mechanisms (Connor, Egeth, & Yantis, 2004). As a consequence, the stimulus that wins the competition will have preferential access to memory systems for mnemonic encoding and retrieval and to the motor systems for guiding action and behaviour (Pessoa, Kastner, &Ungerleider et al., 2002).

Based on the forgoing, selective attention may be an important factor in determining whether memory for a given face will be affected by the presence of other faces. We wondered, when the perpetrator draws attention to himself, say, by being the only perpetrator to say something during the robbery, is memory affected to the same extent by the presence of other people? The answer to this question is not presently known. No previous study investigating face processing capacity limits has systematically manipulated selective attention; therefore, we did so in the present study. Therefore, our primary goal in this study was to investigate the way in which bottom-up stimulus properties (e.g., angry face expression) mediate competitive interactions in VWM. Specifically, we tested the hypothesis that threat superiority will cancel out the set size effect induced by a rise in the number of TBR faces (set size). To address our questions, we begin by reviewing the pertinent literature followed by an overview of our methodology.

Evidence for Anger-Superiority Effect

Recent evidence suggests that competition can be mediated by emotional valence, with angry faces eliciting faster and more accurate responses than neutral or positive faces (see Becker, Anderson, Mortensen, Neufeld, & Neel, 2011) and capture attention even when task irrelevant (Huang, Chang, & Chen, 2011). This tendency, otherwise known as the "Anger-superiority effect" (ASE) has been demonstrated across different paradigms that include the: attentional blink (Dux &Marois, 2009; Maratos, Mogg, & Bradley, 2008; Maratos, 2011); dot-probe (Bradley, Mogg, Falla, & Hamilton, 1998; Bradley, Mogg, & Millar, 2000); visual search (Fox et al., 2000; Hansen & Hansen, 1988; Öhman, Lundqvist, & Esteves, 2001) and change detection (Jackson, Wolf, Johnston, Raymond, & Linden, 2008; Jackson, Wu, Linden, & Raymond, 2009). Despite diversities in their approach and experimental paradigms, conclusions drawn from these studies suggest that the resources required to maintain an accurate representation of different faces in VWM is greater when one face had an angry compared to neutral expression, which in turn, suggest that face processing is oriented towards detecting a threat.

Jackson and colleagues (Jackson et al., 2008, 2009) adopted the change detection paradigm to measure the sensitivity of recognition memory for angry, happy and neutral faces. In this paradigm, participants were briefly presented with a memory display (consisting of a set of objects), followed by a retention interval (often about 1000ms), and then a test display. The task usually requires observers to compare information from the memory and test displays in order to determine whether one or more objects was the same or changed across displays. Test displays may contain a single or multiple items (probe/s) (see Wheeler &Treisman, 2002). Performance in this task is believed to index the extent to which a memory of the first display is formed, encoded and attended (Levin, Simons, Angelone, &Chabris, 2002). As the number of items in the memory display (i.e., set size) increases, observer’s sensitivity to change typically decreases in a monotonic fashion (Wilken & Ma, 2004). Using this paradigm, Jackson et al. (2009) found that significantly more angry face identities can be stored in visual short term memory than happy or neutral faces. This effect is more pronounced at set size of 2 than 4 (Jackson et al., 2009), when expression was present at encoding (Jackson, Linden, & Raymond, 2014) and is thought to reflect activation of a right hemispheric brain network involving the globus pallidus (Jackson et al., 2008).

The findings from Jackson and colleagues revealed an improvement in memory performance especially when the TBR objects has angry compared to neutral or happy expression. However, Jackson and colleagues employed a design that included a single identity in each display. That is, on a given trial, they presented participants with faces depicting the same emotional expression (i.e., angry, happy or neutral). Although this strategy affords control over potential perceptual confounds, it does not allow for a careful examination of the relationship between threat superiority and set size. For instance, do angry faces bias the allocation of VWM resources when multiple faces compete for limited attentional resources? Perhaps given its threatening value, angry faces should be prioritised in the allocation of VWM resources when presented together with neutral faces.

Previous research (e.g., Hansen & Hansen 1988; Williams &Mattingley, 2006) has shown that angry face benefit is not affected by the number of distractors in the search display, indicating an asymmetric distribution of VWM resources across the TBR faces. Thesefindings areconsistent with the notion that stimuli signalling potential threats have a privileged status in the capability of receiving some ‘preattentive’ or unconscious analysis and be more likely to attract attention than non-threatening stimuli (Vuilleumier, 2002). When sufficient attention is devoted to a stimulus, its neural representation will be favoured, leading to stronger neural signals. Indeed, strong neural signals may be essential for visual awareness (Pessoa & Ungerleider, 2005). Consistent with the predictions of the Shared Resource (SR) model of VWM (Bays & Husain, 2008), observers should be able to flexibly allocate attention and memory resources to a variable number of TBR objects. As a result, sensitivity (as measured by *d*’) should be independent of set size.

Previous research has shown there might be capacity limits to the number of objects that can be attentionally prioritised in VWM (Yantis & Johnson, 1990). Therefore, speculatively as the number of TBR faces (set size) increases (set size>2), competition for resources will be greater and the effect of angry faces will diminish. Indeed, data from a neuroimaging study also suggest activation in the amygdala by emotional stimuli is reduced or absent when the competing task is of high load (Pessoa & Ungerleider, 2005). Perhaps if threat superiority is perceived via an interaction between sensory evidence and fast acting amygdala activation, then decreasing the quality of the perceptual information by increasing set size is likely to deactivate the amygdala activation. If this were indeed the case, then *d*’ for angry faces should reduce drastically as set size increases from 2 to 4 faces.The set size manipulation tests (a) the benefits associated with angry face when competition for attentional resources is minimal compared to when it is high, and (b) it discounts any explanations based on automaticity of angry face processing.

The present study was designed in accordance with three criteria.First, we employed the change detection paradigm to investigate the relationship between *N* (set size) and *d*’ (a signal detection theory measure) when participants free-viewed one, two or four faces to remember. The free-viewing task was chosen because it most closely approximates viewing condition in the real world. Secondly, the size of the memory array (set size) was used to manipulate memory load (competition). One, two or four unfamiliar faces were presented in a display that could contain all neutral faces (including the target and distractors), one angry target and neutral distractors and finally, one neutral target/distractor (s) and an angry distractor. By manipulating set size, a theoretical interpretation of the TSE under high competition condition (large set size) could be assessed. Thirdly, photorealistic stimuli were used, controlling for low-level visual features such as open mouth and/or visible teeth. Lastly, we employed the Bayesian analysis (Rouder et al., 2012) to characterise the relationship between threat-superiority and set size.

Method

Participants

A total of 72 naïve undergraduate students (3 females, 7 males, M_{age}26, range 19-48 years) attending University of Leicester in the UK took part in this study. All had normal or corrected-to-normal vision and had no contact lenses. The study was approved by the School of Psychology's ethics committee at the University of Leicester.

Stimuli

20 sets of unfamiliar faces were obtained from The Centre for Vital Longevity Face Database (Minear& Park, 2004). Additional 20 sets of faces depicting angry expression was obtained from the Karolinska Directed Emotional Face database-KDEF (Lundqvist, Flykt, &Öhman, 1998). The KDEF contains pictures of individuals displaying different emotional expressions, including anger. The database has been widely used in studies of emotional face expressions (e.g., Baenninger, 1994; Jackson et al., 2009; Svegar, Kardum, &Polic, 2013). The faces were cropped into an oval to remove the hair using the Adobe Photoshop CS5 (Adobe Systems, San Jose, CA). To control for perceptual differences across faces, both the neutral and angry faces were grayscaled. To limit the low-level visual features, none of the selected faces has open mouth and/or visible teeth. All the faces measured 219 x 273 pixels (resolution 72dpi) and were further rescaled to 348 x 360 pixels using the height x weight (H:W) ratio of the display monitor. Trials could contain one, two or four faces at locations selected randomly from 0, 90, 180 and 270 degrees on a virtual circle at an eccentricity of 7.52°. Faces were presented in full-face frontal view on a gray background with a screen resolution of 1024 x 768 pixelsand subtended a visual angle of 8.6° x 9.0°.

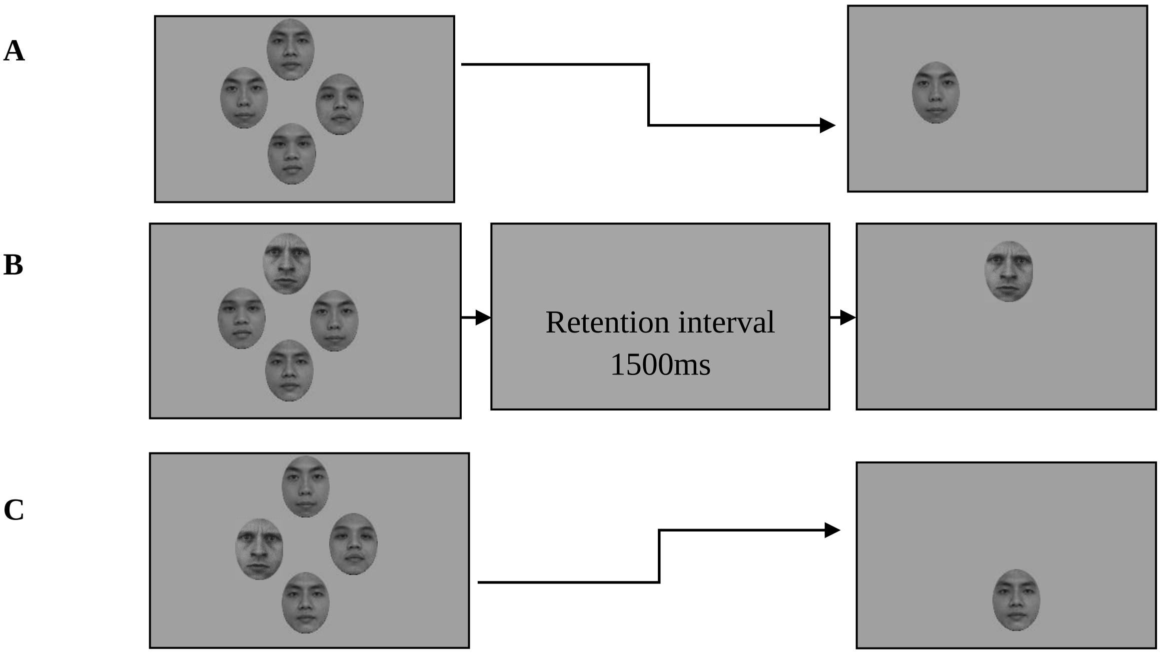
Apparatus

Stimulus presentation and data recording were controlled using custom-built software in MATLAB (R2010a, © The Mathworks, Inc.) with add-ons from Psychophysics toolbox (Brainard, 1997; Pelli, 1997). Stimuli were presented on a 21” HP Trinitron P1130 CRT Monitor with a screen resolution of 1280 x 1024 pixels and a refresh rate of 75Hz.

Procedure

In all conditions, the experiment used a factorial design to manipulate trial type (target-present or -absent), expression (neutral, angry, invalid) and set size (1, 2 or 4 faces).All participants were tested individually in a darkened quiet room and viewing distance was maintained at 57cm using a fixed chin rest.

Following a successful calibration and validation sequence, an instruction appeared on the screen prompting participants to press any key to begin the trial. Participants were first presented with a short practice session (15 trials) to familiarize themselves with the procedure. The experiment contained three different conditions. In the baseline condition (Figure 2A) the participants were presented with a memory display that could contain one, two or four neutral faces and at test, a single probe (neutral face) was presented.Memory and test displays were separated by a retention interval of 1500ms. In the angry condition (Figure 2B) the procedure was identical to the baseline condition except that one of the faces (i.e., the target) had an angry expression. For example, the display contained the target with an angry expression and a neutral distractor (set size 2) or distractors (set size 4). At test, an angry face (probe) was presented.In the invalid condition (Figure 2C) one of the distractors has angry expression while the remaining faces in the display including the target have neutral expressions. At test, a single face (neutral face) was presented. To control for variability in encoding time, the duration of the memory display was determined by the set size with each face allocated 500ms (i.e., 500, 1000 and 2000ms for set sizes 1, 2 and 4 respectively) (see Alvarez & Cavanagh, 2004; Awh, Barton, & Vogel, 2007; Chen, Eng, & Jiang, 2006; Jackson & Raymond, 2008; Jiang et al., 2008). Previous research has shown that on average, 2000ms exceeds visual search response times for an array of four faces (Eng, Chen, & Jiang, 2005; Jackson & Raymond, 2008). The test display remained visible on the screen until a response was made. In the test display, a single face (probe) was presented for retrieval from VWM (see variations above based on condition). In 50% of trials, the probe contained the target (target-present trials). In the remaining 50%, the probe contained a different face not present in the memory display (target-absent trials). Participants responded “same” if they thought the probed face matched one of the faces held in VWM (no-change trials) and “different” if it did not match (change trials). Each participant completed 360 trials in one experimental session, with the trials in each condition interleaved and counterbalanced across blocks and participants. In order to control for spatial uncertainty, the position of the target and distractors on each trial was randomized.There were four blocks of trials, each consisting of 90 trials. Participants were offered short breaks for rest (usually after every 180 trials). Each block took approximately 10 minutes to complete. No feedback was provided after each response was obtained.



Memory display (500ms x set size) Test display until response

Figure2. Schematic of the experimental set-up. (A) Baseline condition: memory display containing 4 faces. All the faces have neutral expressions. (B) Angry condition: memory display could contain 1, 2 or 4 faces (an angry target face in the midst of neutral distractors). (C) Invalid condition: memory display could contain 1, 2 or 4 faces (neutral targets and an angry distractor). The retention interval was 1500ms and the test display contains a single probe: neutral face in baseline and invalid condition; angry face in the angry condition.

Data analysis

Behavioural Data Analysis: The change detection ("same-or-different") performance by set size and expression condition was analyzed using the signal detection theory (SDT) measures of target discriminability (*d*'). The SDT analysis provides a means of dissociating changes in recognition memory associated with discriminability on one hand, and decision bias on the other. Both *d*' and percent correct were calculated for each participant across set size and expression conditions. However, only *d*' were subjected to analysis while the mean percent correct scores are listed in Table 1. A separate 2 (trial type: target-present vs. target-absent) x 3(expression: baseline, angry target, angry distractor) x 3 (set sizes: 1, 2, 4) within participants ANOVA were conducted with sensitivity *d'* as the repeated measures. The observed hit and false alarm rates are displayed in Table 2.

To quantify the observer's performance and the sensitivity of recognition memory *d*', we used an inverse Square-root function (Burmester& Wallis, 2012, Salmela& Saarinen, 2013). This model based on the Sample-size model assumes that precision is inversely related to set size and proportional to the square root of 1/N (Salmela& Saarinen, 2013). According to the Sample-size model, performance in a memory or search task is dependent on the total amount of information or samples *M*that the observers can process from the scene (Palmer, 1990; Palmer, Ames, & Lindsey, 1993). In the absence of an attentional bias, *M* is equally distributed among *N* objects in the display, resulting in an integer number of samples for each object, $K=M/N$. According to this account, samples for all objects follow a Gaussian probability distribution with equal variances. As set size increases, attentional resources during encoding and maintenance are distributed more thinly, decreasing the number of samples and increasing the variance of the distribution for each object (see equation 1).

In the signal detection theory, sensitivity *d*' (equation 2) is derived from the observed proportions of hits and false alarms divided by their common standard deviation (Wickens, 2002). Increasing *N*, therefore, reduces *d'* via an inverse square root relationship (equation 3). This simple relationship has been shown to accurately predict the decrease in *d'* as set size increases for objects defined by variation on a single feature (Burmester& Wallis, 2012; Salmela&Sarrinen, 2013). Whether this result generalizes to complex stimuli during a test of face recognition memory has yet to be determined. A square-root relationship was therefore used to characterize the inverse relationship between *N*(set size) and *d'* when *N* was fixed (Equation 4) or multiplied by a free-parameter (Equation 5).

$$\sigma^2 \propto N \text{ .... } (1)$$

$$d' = z(hits) - z(FA)/\sigma \text{ .... } (2)$$

$$d' \propto N^{½} \text{ .... } (3)$$

$$d'_p = \sqrt{d'_1 * \frac{1}{N}} \text{ .... } (4)$$

$$d'_p = \sqrt{d'_1 * \frac{1}{N * a}} \text{ .... } (5)$$

where d'_p denotes predicted d', N denotes the number of faces in the memory display, d'_1 denotes the observed d' at set size 1 and a is a free-parameter.

In addition to the above, the sample-size model provides a basis for quantifying changes in distribution of resources to objects in VWM in response to stimulus-driven shifts of attention (Bays and Husain, 2008; Desimone & Duncan, 1995). We compared model fits for the full (fixed *N*) and reduced (variable *N*) models. The reduced (*N* as a free-parameter) inverse square root model was used to account for additional source of errors associated with the encoding and maintenance of unfamiliar faces. The reduced *N* model was fitted with a least square solution, which iteratively varies *N* to optimise the fit between the observed and predicted *d*' by set size functions. In order to determine the extent to which the data points fit the model, the coefficient of determination, known as R^2 was adopted. The R^2 provides a goodness-of-fit measure for the full (fixed N) and reduced (variable N) models, which is used to compare model fits for each observer when *N* was fixed or free to vary (Nadjusted). R^2 is calculated using the formula:

$$R^2 = 1-[\mathrm{Sum}_{(i=1 \text{ to } n)} \{w_\mathrm{i}(y_i-f_i)^2\}]/[\mathrm{Sum}_{(i=1 \text{ to } n)}\{w_i(y_\mathrm{i}-y_\mathrm{av})^2\}] = 1- \mathrm{SS}_\mathrm{residuals}/\mathrm{SS}_\mathrm{total}$$

Where n is the number of observations, $y_\mathrm{i}$is the observed data, f_i is the modelled or predicted values from the fit, y_av represents the mean of the observed data $y_\mathrm{i.}$ w_i represents the weighting applied to each data point, typically w_i=1. $\mathrm{SS}_\mathrm{residuals}$is the residual sum of squares and represents the degree of inaccuracy when the best model is fitted to the data. $\mathrm{SS}_\mathrm{total}$is the total sum of squares and represents how good the mean is as a model of the observed data, f_i (Field, 2005).

Eye movement Data Analysis: For eye movement data, the dependent measures used were the number of fixations and length of time participants spent looking at the target location (fixation duration). Both the number and duration of fixations were entered into a separate repeated-measure ANOVAs with expression (baseline, angry, invalid) and set size (1, 2 or 4) as within subject factors. The average number of fixations and fixation durations made on each target face by condition are presented in Table 3.

Results

Behavioural data

Mean *d*'across conditions were: *M*=1.69 (*SE*=.26), *M*=2.15(*SE*=.24), *M*=1.54(*SE*=.23) for the baseline, angry and invalid conditions respectively. Target discriminability was significantly influenced by the emotional expression [F (2, 18) = 11.04, p=0.001, $\eta^{\rho 2}$ =.55] with d' for angry faces higher than those for neutral faces ($p<0.05$). Mean d' also reduced as set size increased from 1 to 4 (M=2.32, SE=.31, M=1.75, SE=.23, M=1.29, SE=.18 for set sizes 1, 2 and 4 respectively). The ANOVA confirmed the significance of this result yielding a main effect of set size [F (2, 18) =30.09, $p<.001$, $\eta^{\rho 2}$=.77]. There was a condition by set size interaction [F (4, 36) = 3.75, p=0.01, $\eta^{\rho 2}$=.29]. Bonferroni corrected post-hoc analyses confirmed d' for angry faces was larger at set size 2 (M=2.45, SE=.33) than set size 4 (M=1.59, SE=.17) ($p<0.02$). However, there was a significant set size effects in baseline and invalid conditions, with d' decreasing as the number of TBR faces increased from 1 to 4 (pairwise comparisons had $p>0.05$ across set sizes).

Modelling d' as a function of emotional expression and set size

To assess differences in sensitivity by set size functions across each experimental condition, the inverse square root relationship was calculated for each observer along with the best fitting N (Nadjusted). Table 4 provides a correlation coefficients and ANOVA statistics for d' by set size functions when N was fixed and entered as a free-parameter (Nadjusted). As Table 4 reveals, R^2 statistics are better for the Nadjusted than the N models across the three conditions, yielding a significant F-test ($p<0.001$). Thus, allowing N to vary leads to an increase in R and subsequently, a better fit between the observed and predicted d' by set size functions. The mean observed against the mean predicted d' by the sample-size model as a function of set size (unadjusted) and expression conditions is plotted in Figure 3. As Figure 3 (dashed line) reveals, the reduction in performance as a function of set size was well predicted by the square root function. For neutral faces (baseline), the predicted model for the N is a fairly good approximation of the data: the mean observed d'falls below and above that predicted at set sizes 2 and 4 respectively. Allowing N to vary increases the fit and yields mean N_{adjusted} of 1.12 (see Table 4) which is greater than predicted by the sample size SDT model for simple stimuli(see Equation 4; Salmela& Saarinen, 2012). For angry targets, the reverse was true: observed was higher than the predicted d' at set sizes 2 and 4. Allowing N to vary increases the fit and yields an N_{adjusted} of 0.61, which is 0.39 lower than predicted for simple stimuli. For the angry distractor (invalid) condition, mean observed d' falls below the predicted d' for simple stimuli at set size of 2 and 4 respectively. Allowing N to vary increases the fit and yields an Nadjusted of 1.69, which is 0.69 higher than predicted for simple stimuli.

Over all, the fitting procedures suggest that sensitivity is inversely related to set size in the baseline and invalid condition but not in the angry condition. The best fitting adjusted N not only confirmed a considerable difference across the three conditions (mean *N*adjusted = 1.12, 0.61 and 1.69 for baseline, angry and invalid respectively), but also suggested a benefit for angry compared to neutral faces. Importantly, having an angry face as a distractor reduces distractor interference by approximately 0.6 (mean difference, Baseline=1.12, invalid=1.69). This in turn, suggests that angry faces exhaust the resources available to process neutral faces, leading to weakened representations of neutral faces.

Table 1

Mean percent correct as a function of emotional expression and set size. Standard errors of the mean are presented in parentheses.

Baseline			Angry_nD			N_AngryD		
1	2	4	1	2	4	1	2	4
.83(.04)	.72(.03)	.69(.04)	.84(.06)	.83(.04)	.75(.02)	.81 (.04)	.72(.03)	.67(.02)

Table 2

Mean proportion of Hits and False Alarms (and Standard Error) as a function of emotional expression and set size

	Baseline			Angry_nD			N_AngryD		
	1	2	4	1	2	4	1	2	4
Hits	.85(.03)	.72(.05)	.63(.05)	.82(.06)	.84(.04)	.71(.05)	.84 (.05)	.73(.05)	.65(.04)
FA	.21(.07)	.27(.08)	.24(.07)	.15(.05)	.18(.08)	.19(.05)	.22 (.07)	.29(.06)	.31(.06)

Table 3

Average Fixation duration and Fixation Number (Standard Error) as a function of emotional expression and set size

		Baseline	Angry_nD			N_AngryD			
124		124124							
FD	317(16.7)	282(16.4)	256(14.3)	318(17.7)	265(10.5)	244(11)	307(15.7)	275(11.2)	255(10.2)
FN	58.9(4.1)	57.3(5.4)	70(3.2)	63(4.4)	60(5.1)	77(6.3)	38(2.7)	59(4.2)	72(4.1)

Table 4

Correlation coefficients and ANOVA statistics for *d*’ by set size functions with N-fixed and N-entered as a free-parameter.

Condition	$d'_1 N_{adj*}$	$R^2\ N$	$R^2 N_{adj}$	F	p-value
Baseline	2.30	1.12	0.87	0.9226.88	<0.001
AngryT	2.38	0.610.47	0.9231.32		<0.001
AngryD	2.29	1.69	0.81	0.9685.01	<0.001

$*N_{adj} = \mathrm{N}_{adjusted}$

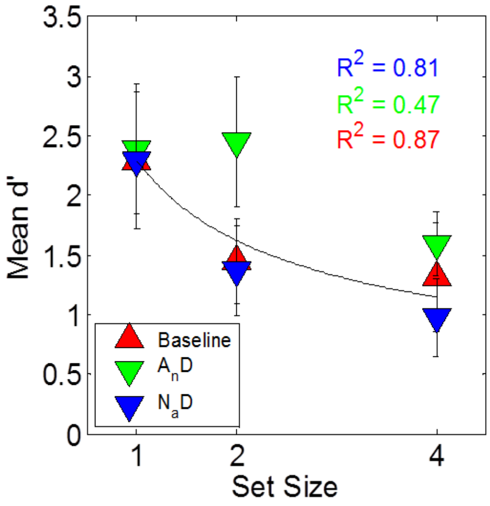


Figure3. Mean observed *d*’ by set size functions for angry and neutral faces and predicted *d*’ at each (unadjusted) set size. The error bars represent standard errors of the mean. The angry condition is denoted as “A_nD” and the invalid (angry distractor) condition is denoted as “N_aD”.

Eye movement data

Figures 4A and 4B depict the number and duration of fixations as a function of expression and set size. The analysis of fixation duration and fixation revealed no differences across conditions (all *p*s>0.05).There was no correspondence between the oculomotor parameters (i.e., the number and fixation of duration) and *d*’ analysis. Participants did not fixate more to the angry compared to neutral faces. This suggests that the relationship between emotional expression and VWM is not mediated by overt attentional effects.

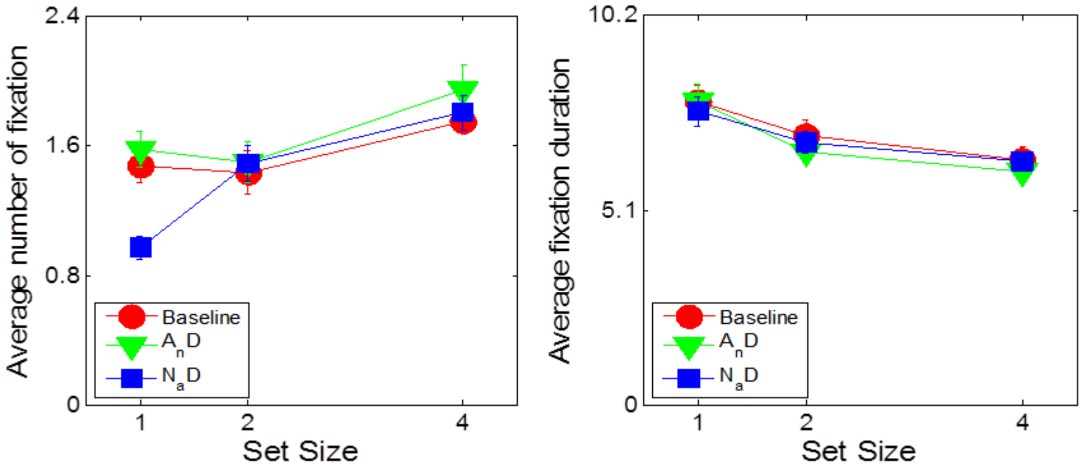


Figure4(A) Average number of fixations made to the target location as a function of emotional expression and set size. (B) Average fixation duration (in msecs) as a function of emotional expression condition and set size. Error bars represent ±1 standard error of the mean.

Discussion

The current study investigated the relationship between threat superiority and set size and employed the inverse square-root function to characterize this relationship. It also examined whether the angry face benefit was driven by saccadic sampling (i.e., overt attention) and then measured the sensitivity of recognition memory for neutral faces when one of the distractors has an angry expression. Consistent with the SR models of VWM (Bays & Husain, 2008), target discriminability (as indexed by *d*’) decreased for neutral faces as the number of TBR faces (set size) increased from 1 to 4, reflecting the distribution of attentional resources during the encoding and maintenance of TBR faces. Estimates of *N*adjusted revealed a decrease in *d*’ that is larger for faces than stimuli defined by variation on a single feature (Salmela& Saarinen, 2013). This suggests the Sample-size model (Burmester& Wallis, 2012) approximates the observed *d*’ by set size functions pretty well. When the target had an angry expression, however, sensitivity (as indexed by *d*’) was found to be greater than faces with neutral expression. This effect was more pronounced at set size of 2 than 4, replicating previous findings (e.g., Jackson et al., 2009). Jackson and colleagues found that recognition memory was more accurate for angry compared to neutral or happy faces. At set size of 2, the increase in *d*’ for angry faces appeared to be largely independent of a decrease in *d*’ for the neutral face, which in turn, suggests an expansion of resources available to maintain angry faces.

Why does the angry face benefit emerge at set size of 2 and not 4? Perhaps there are explanations. First, as Jackson and Raymond (2008) argued, observers may only be able to store two face identities at any one time in VWM. Secondly, evidence from the face recognition literature suggests configural mechanisms support upright face processing (see Hole & Bourne, 2010). However, with increase in memory load (i.e., set size), the benefits associated with configural information is reduced because observers cannot maintain four face representations (Cheung & Gauthier, 2010). Thirdly, when sufficient attention is devoted to a stimulus, its neural representation will be favoured, leading to stronger neural signals. Therefore, perhaps with the increase in competition due to neuronal noise (large set size) angry faces tend to receive weaker neural signals, and the resolution required to maintain emotion became more thinly distributed. Specifically, neuroimaging studies (e.g., Vuilleumier et al., 2001) have previously demonstrated the specialized role of amygdala (a brain structure thought to be responsible for emotional processing) in the detection of emotionally relevant stimuli, even when the stimuli were masked and outside an individual’s conscious awareness (Morris et al., 1998). Perhaps if threat superiority is perceived via an interaction between sensory evidence and fast acting amygdala activation, then decreasing the quality of the perceptual information by increasing set size is likely to deactivate the amygdala activation.

Our findings are inconsistent with those reported by Williams and Mattingley (2006), which showed that the benefits associated with angry faceswereindependent of set size. Perhaps the difference between the two studies could lie in the stimuli material used. Specifically, Williams and Mattingley used angry faces that depicted open-mouth and/or visible teeth. This type of stimuli has been shown to drive efficient search, especially when the same stimuli sets were used repeatedly across many trials (Becker et al., 2011). Indeed, differences in stimuli material have been shown to account for inconsistencies in the results of visual search studies for emotional faces (for reviews, see Juth, Lundqvist, D., Karlsson, A., &Öhman, 2005; Savage, Lipp, Craig, Becker, &Horstmann, 2013), thus suggesting that the reported threat superiority effect-TSE (e.g., Williams &Mattingley, 2006) may in fact, reflect low-level visual features associated with the stimuli material, rather than emotional expression.

Our second goal in this study was to determine whether the angry face benefit observed in the present study was driven by oculomotor sampling (i.e., overt attention). Our data did not support this. The eye movement analysis revealed a lack of relationship between threat superiority and fixation locations as measured by the number and duration of fixations: Participants did not make longer fixations or look more to the location occupying the angry target than to locations occupying a neutral target. This suggests that attentional capture underpinning the angry face benefit is not automatic in driving eye movements, thus replicating previous findings (Barratt &Bundesen, 2012;Thomas, Jackson, Linden, & Raymond, 2010). In fact, the present findings dissociate bias that drives oculomotor sampling behaviour from those underpinning advantage for sensitivity and are consistent with previous research that suggests eye movement and selective attention are not always linked together (Posner et al., 1978). Specifically, Posner and colleagues reasoned that attentional spotlight is not fixed and can be oriented toward relevant stimuli-without necessarily moving the eyes. This suggests that attention is not always directed to the gaze location.

Finally, we measured the sensitivity of recognition memory for neutral faces when one of the distractors had an angry expression. Importantly, we found that when one of the distractors had an angry expression, the resources required to maintain neutral faces became more thinly reduced. The best-fitting adjusted *N* not only confirmed the considerable difference in performance across conditions, but also suggested that the cost of maintaining neutral targets was higher when attention is oriented to an angry face. This suggests that angry faces exhaust the resources available to process neutral faces. The findings complement and extend previous research using schematic faces (e.g., Huang et al., 2011) and further, confirmed the role of emotional valence in the allocation of selective attention in VWM.

To summarize, the results from the present study suggest that when competition for attentional resources is low (set size=2), the stimulus that is emotionally salient because of its threatening value will win the competition for neural representation. This advantage appears to be largely independent of saccadic sampling and suggests the benefit occurred during maintenance rather than encoding. Importantly, because set size increases the distribution of resources during encoding (indexed by reduction in fixations duration) and maintenance, the observed interaction between set size and threat superiority effect suggests that decreasing the quality of the perceptual information available by increasing set size, is likely to decrease threat superiority because it reduces the information driving the activation of the amygdala.

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