Can bottom-up processes of attention be a source of "interference" in situations where top-down control of attention is crucial?

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Abstract

In this study we investigate whether emotionally engaged bottom-up processes of attention can be a source of "interference" in situations where top-down control of attention is necessary. Participants were asked to monitor and report on a video of a war scenario showing a developing battle in two conditions: emotionally positive and emotionally negative. Half of the participants (n = 15) were exposed to task-irrelevant pictures of positive emotional valence embedded within the scenario; the other half were exposed to task-irrelevant pictures of negative emotional valence. Sensitivity and bias scores were calculated using Signal Detection Theory. Overall, task accuracy scores were dependent upon the valence; negative pictures had an adverse effect on performance, whereas positive pictures improved performance. We concluded that negative emotional pictures interfered with top-down control of attention by attracting competing bottom-up processes of attention. We found the opposite effect for positive emotional stimuli.

1. Introduction

It is widely accepted that the main function of attention is to enhance information that is relevant and attenuate information that is not (Maunsell & Treue, 2006; Pinto et al., 2013). Two main types of attention are commonly distinguished in the literature: bottom-up or *stimulus-driven* and top-down or *goal-oriented* attention. The former is determined by the physical characteristics of the information attended to and the latter by the observer’s current goals (Carrasco, 2011; Corbetta & Shulman, 2002; Desimone & Duncan, 1995; Kastner & Ungerleider, 2000). Although each system has been extensively studied (Carrasco, 2011), it is not yet well understood how they interact with each other (McMains & Kastner, 2011). In this study we investigate whether emotionally engaged bottom-up processes of attention can be a source of “interference” in situations where top-down control of attention is required to perform a task. For example, when a soldier is asked to report on a live video feed of an evolving battle or when a doctor has to perform complex medical procedures in the middle of a natural disaster, these tasks normally require strong top-down control of attention so that the relevant information is actively sought out, selected and monitored in line with the goals. We argue that this top-down process can be disrupted in the presence of task-irrelevant stimuli with high potential to engage automatic bottom-up processes of attention. A special class of such stimuli believed to capture bottom-up attention due to their evolutionary salience are threat-related stimuli, such as mutilated bodies, snakes or angry faces (Öhman, Flynkt, & Lyndqvist, 2000; Ohman & Mineka, 2001).

Few studies have looked into this interference directly. Wilson, de Joux, Finkbeiner, Russell, & Helton (2016) assessed the impact of anxiety-provoking stimuli on the Sustained Attention to Response Task (SART; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997). Using task-irrelevant negative and positive images which were interleaved with SART they found that negative images had a slowing effect on performance. Similarly, Ossowski, Malinen, & Helton (2011) found that irrelevant negative images, but not neutral images, reduced performance in a vigilance task; a finding also replicated by Helton & Russell (2011). Hartikainen, Ogawa, Soltani, & Knight (2007) used a visual-discrimination task and found that unpleasant task-irrelevant stimuli interfered more with the left visual field attention capacity.

Other studies, however, have reported conflicting results. Robinson, Krimsky, & Grillon (2013) found that the threat of shock significantly reduces errors of commission on the no-go SART trials relative to the safe condition, suggesting that the negative emotional condition facilitated by threat can actually improve performance, especially when that performance relies on inhibition. This finding was replicated by Wilson, Russell, & Helton (2015), who also suggested that anxiety provoking stimuli can have positive effects on some aspects of cognition, such us inhibition.

Although there is evidence that bottom-up and top-down attentional systems can operate independently (Pinto et al., 2013), many researchers agree that both the individual's goals and stimulus-driven properties play important roles in attention, each biasing competitive interactions among stimuli (Desimone and Duncan, 1995; Beck and Kastner, 2009).

Furthermore, the top-down and bottom-up attentional systems have been associated with the activity of specific neuronal structures in the visual cortex, with area V1 only responding to bottom-up, saliency information, area V2 responding to top-down modulations and area hv4 facilitating the convergence between the two attentional systems (Melloni, Van Leeuwen, Alink, & Müller, 2012). Other areas of the brain, such as the fronto-parietal network, have also been identified as essential in facilitating the activity of both types of attentional processes (Katsuki & Constantinidis, 2014). The involvement of the early visual cortex (areas V1, V2 and hv4) and fronto-parietal networks in the integration between bottom-up and top-down attentional controls suggests that both systems are active and interact with each other from early on in the processing of sensory information.

To summarise, research evidence suggests that the presence of task-irrelevant negative emotional stimuli can interfere with the activity of top-down attentional processes. While negative emotional stimuli can engage bottom-up attentional processes, it is not clear whether positive emotional stimuli have the same effect. If they do, it is not clear whether the process of interference will be similar to that of negative emotional stimuli, or of similar intensity.

To investigate these questions directly we have developed a task that relies on top-down attentional processing for success. Participants were tested either under the presence of task-irrelevant negative emotional stimuli or task-irrelevant positive emotional stimuli. To measure performance we employed Quantitative Analysis of Situation Awareness (QASA) (Edgar & Edgar, 2007) based on Signal Detection Theory (Green & Swets, 1966) . Widely used in psychological studies since the 1960s, Signal Detection Theory (SDT) provides precise terms and mathematical notation that can be applied whenever two possible stimulus types must be discriminated, whereas QASA provides a useful cognitive theoretical framework within which to interpret the data. The essential measures that SDT provides are Sensitivity and Bias. Sensitivity indicates how signal is discriminated from noise, whereas Bias indicates the tendency to accept or reject information as signal or noise (Figure 1). In this task and within the context of SDT theory, a strong positive Bias means that people are rejecting most information as false, and also indicates a strong effect of unrelated emotional information (bottom-up attention) on task performance (which relies on top-down attentional monitoring). We argue that increased interference from bottom-up attentional systems causes a deterioration of top-down task performance. Therefore, we expect people will adapt by becoming more cautious (Shiv, Loewenstein, Bechara, Damasio & Damasio, 2005). In SDT terms, this means that Bias becomes more positive (moves to the left on Figure 1).



Figure 1. Theoretical overlapping distributions of the internal representational strengths for true (signal; shown as a solid curve) and false (noise; shown as a broken curve) items of information. The Bias is represented by the grey vertical line with arrows showing that Bias can move left and become more positive or right and become more negative. If Bias moves in the positive direction, less of the true information will filter through, but also less false information. Conversely, if Bias moves in the negative direction, more of the true information will filter through, but also more false information.

Furthermore, we expect to find a relationship between Sensitivity and Bias scores. High Sensitivity, which indicates high performance accuracy, indicates a good functioning of top-down attentional monitoring and less of an interference effect from bottom-up attentional systems. In this case we expect the Bias to move towards the negative end of the scale.

The task we developed for this study is loosely based on that used by Edgar, Edgar, & Curry (2003). It consists of a scripted war-fighting scenario with the participant viewing the scene from the vantage point of one of the combatants. Participants respond with either true or false to 48 statements presented about the war-fighting scenario. Separating true from false statements accurately is the Sensitivity part and the tendency to report true or false independent of the actual truth or falseness of the item is Bias. The emotional stimuli consist of negative and positive emotional images selected from the International Affective Picture System (Lang, Bradley, & Cuthbert, 2005).

2. Methods

*2.1 Participants***.**

30 participants were randomly selected (opportunity sampling) from psychology undergraduate students at the University of Gloucestershire. Participants were randomly allocated into two groups of 15 participants, and each group participated in one emotional condition: positive (mean age = 24.60 SD = 3.48, 4 female); negative (mean age = 23.33, SD = 3.62, 3 female).

All participants had self-reported normal or corrected-to-normal vision. All participants signed a consent form accepted by the University of Gloucestershire prior to taking part in the study. Participants were not offered any monetary reward for taking part.

2.2 *Materials*

*2.2.1 IAPS Images.*

Forty colour pictures were selected from the IAPS dataset (Center for the Study of Emotion and Attention, 1999), consisting of twenty positive and twenty negative pictures based on valence (a bipolar continuum with negative and positive poles measured as hedonic distance from neutral) and arousal (a continuous axis increasing from low to highly arousing). Both sets were selected to be the most polarised exemplars in their respective subcategories. A further six images were selected which were used to standardise picture processing for all participants prior to starting the main task (emotional calibration set) and depicted various landscapes (Table 1). The size of stimuli is 768 x 1024 pixels for all images.

All images were processed for luminance and contrast information using MATLAB script (rgb2gray function for extracting luminance values (rgb2gray, 2016) and mean2 function for extracting contrast values (mean2, 2016)). Two independent-samples t-tests were conducted to compare mean luminance and contrast values in positive and negative image sets. There was no significant difference in the luminance values for Positive (M=93.16, SD=37.5), and Negative (M=86.08, SD=41.14), *t*(38) = 0.57, p = 0.57 image sets; and no significant differences in contrast value for Positive (M=0.08, SD=0.02) and Negative (M=0.07, SD=0.03), t(38) = 0.77, p = 0.45 image sets.

When using image sets there is also the concern of variation in content information. However, as yet there is no widely agreed procedure for matching content information. Our approach to selecting images followed the findings by (Colden, Bruder, & Manstead, 2008) that images depicting humans and animals in the IAPS image sets are over-represented in the high arousal/positive and high arousal/negative areas of affective space as compared to inanimate pictures. Therefore, only images with human or animal content were selected. The images in the positive set were selected from the following categories: Babies, Father, Mother, Family, Children and Erotic Couples. The images in the negative set were selected from the following categories: Snake, Spider, PitBull, Shark, Mutilations, Burn Victim, Attack, Aimed Gun, Sliced Hand. As expected, the valences of the image sets are significantly different, measured on the IAPS scale from 1 (highly unpleasant) to 9 (highly pleasant). An independent-samples t-test was conducted to compare normative arousal scores for negative and positive emotional conditions. There was a significant difference in the scores for positive (M = 5.44, SD = 1.07) and negative (M = 6.79, SD=0.41) conditions; t (38) = -5.26, p < 0.05. These results suggest that arousal overall was higher for negative images.

Table 1. *Details of the image sets used.* Mean and standard deviation (sd) for arousal, valence, luminance and contrast are given for Calibration, Positive and Negative sets. Luminance can take values in the range [0,255]. Contrast is calculated as Root Mean Square. Finally, identifier numbers for each IAPS image are given in the bottom row.

|  |  |
| --- | --- |
|  | Calibration (n= 6) Positive (n= 20) Negative (n = 20) |
| Arousal (mean/sd) | 4.01/*0.96* 5.4/*1.07* 6.79/*0.41* |
| Valence (mean/sd) | 7.45/*0.56* 7.3/*0.66* 2.31/*0.84* |
| Luminance (mean/sd) | 129.31/*24.57* 93.16/*37.50* 86.08/*41.14* |
| Contrast (mean/sd) | 0.07/*0.03* 0.08/*0.02* 0.07/*0.03* |

|  |  |  |  |
| --- | --- | --- | --- |
| IAPS Image Identifiers | 5760,5780,5750,  7492,5825,5725 | 2050,2070,2080,2160,  2165,2170,2311,2340, 2341,2360,4650,4651,  4652,4658,4659,4660, 4664,4670,4680,4690 | 1050,1120,1201,1300,  1930,3000,3010,3051, 3060,3071,3080,3102,  3110,3130,3530,6260, 6350,6510,6540,9405 |

2.2.2 *State Anxiety Inventory*

To directly gauge the arousal effect that the emotional stimuli had on participants, we used the State Anxiety Inventory (SAI) subset of the Spielberger’s State/Trait Anxiety Inventory (Spielberger, 1989). SAI was administered before and after the completion of the task.

2.2.3. Quantitative Analysis of Situation Awareness (QASA).

The QASA approach uses true/false statements drawn from the situation of interest and an analysis based on signal detection theory to compute sensitivity and bias. The best-known measures of sensitivity and bias are *d'* (sensitivity) and ß (bias). These signal detection measures assume that the item representation strengths are Gaussian distributions with similar variances. If these assumptions are violated, then the utility of *d'* and ß are compromised (Pastore et al., 2003). Although the underlying evidence distributions across a variety of situations are likely to be Gaussian, it appears far less likely that such distributions will have equal variance (Ratcliff, Sheu, & Gronlund, 1992; Stretch & Wixted, 1998; Swets, 1986). Furthermore, as sensitivity drops to zero (the individual is guessing), the bias also drops to zero (Snodgrass & Corwin, 1988). Also, with small samples, the sampling distribution of *d'* is likely to be neither Gaussian, nor unimodal (Miller, 1996). *d'* can also be undefined if an individual answers all the probes correctly. The value and variance of *d'* are affected by the convention (such as that suggested by Murdock Jr. & Ogilvie, 1968) used to handle the issue of *d'* being undefined (Miller, 1996).

Due to the issues with *d'* and ß, QASA applies signal detection measures widely-used in studies of recognition memory (e.g. Donaldson, 1996); namely A' (Pollack & Norman, 1964) as a measure of sensitivity and B'' as a measure of bias. A' makes fewer assumptions concerning the sampling distribution than *d',* tends to be relatively more robust when sample sizes are small (Verde et al., 2006).

A' and B'' were calculated using formulae described by Stanislaw and Todorov (1999):

where *H* = ‘Hit’ rate; *F* = ‘False alarm’ rate and max(*H,F*) = Either *H* or *F*, whichever is greater.

A' will be in the range 0 to 1 (with 0.5 indicating an inability to tell true from false information) and B'' will be in the range -1 to +1. For ease of plotting and interpretation the QASA tool rescales both measures to a scale running from -100 to +100. Following rescaling, the zero points correspond to an A' of 0.5 and a B'' of zero. The resultant scores and interpretations are given in Table 2.

Table 2. Interpretations of the sensitivity and bias scores provided by the QASA tool.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Score** | **Sensitivity - A'** |  | **Bias - B''** |  |
| **Positive (max +100)** | Good sensitivity. Can tell true information from false: higher score is better. |  | ‘Strict’ bias. Tendency to reject information as false even if true. The higher the score the greater the tendency to reject information as false. |  |
| **Zero** | No SA – guessing? |  | No bias towards accepting or rejecting information. A ‘neutral’ attitude. |  |
| **Negative (max -100)** | Misguided. Believes false information is true and *vice versa.* More negative is worse. |  | ‘Lax’ bias. Tendency to accept information as true even if false. The more negative the score the greater the tendency to accept information. |  |

One feature of signal detection theory generally, and the QASA approach particularly, is that it is possible to have a negative sensitivity score. This suggests that either the participant has completely misunderstood the instructions for the task, or that their awareness of the situation they are in is wrong. That is, it is not that they have no awareness of the situation – they have an incorrect awareness and this may, in turn, underpin serious performance errors such as friendly fire (Edgar & Edgar, 2007).

Note that the amount of information accepted from a situation (based on the model shown in Figure 1) is determined by a criterion representation strength. Items of information with a representation strength greater than that criterion are accepted, those below are rejected. The criterion point and sensitivity are independent: one can change without having any effect on the other (for a comprehensive discussion of this issue see Pastore, Crawley, Berens, & Skelly, 2003). This is one of the key features of signal detection theory. Although Bias in QASA is derived from the criterion point it is not the same as the criterion - and it is not independent of the underlying signal and noise distributions. Bias is an indication of the proportion of information accepted/rejected, based on the position of the criterion point with respect to the underlying distributions. If either the criterion point or the underlying distributions change, the amount of information accepted/rejected will also change. In a simulation of a real-world task, such as that assessed in this study, we believe that it is of greater utility to know how much information is accepted/rejected (bias), rather than the position of the criterion point.

There is one caveat: when the hit rate (HR) equals the false alarm(FA) rate (chance performance), the calculated criterion (c) for different hit/false alarm pairs will scale but B’’ will not. That is, apparent changes in B’’ may reflect changes in sensitivity rather than bias. To control for this eventuality, we will use a dual approach: 1) screen the data for participants that have equal HR and FA scores and 2) for any reported significant difference of B’’ across conditions, the difference in the criterion point, which is independent from sensitivity, will also be considered. If the criterion values are also statistically different, then the difference in bias between the groups is unlikely to be an artefact of a difference in sensitivity between the groups.

*2.2.4 The Task*

The task consisted of a war-fighting scenario. The scenario was comprised of 408 slides, each slide presenting one image. All images were extracted from a recording of a video game. The order in which the images were extracted was retained during presentation to maintain the coherence of the original oning.tion has predictable effec they cted to "n of the taskinndition and DispenS type of functioning.tion has predictable effec scenario as it was in the video. Henceforth we will refer to the presentation of the images as the “scenario” to indicate that the image presentation showed an unfolding situation. Twenty IAPS emotion appropriate images (Lang et al., 1997, 2008) were interleaved with the scenario at pseudo-random intervals of 8-13 slides. Each image stayed on screen for 1s, presented at 100ms intervals.

2.2.5 *Computer Equipment.*

The task was administered through a computer screen using e-prime software (e-prime version 2.0, running on a Dell PC, using Microsoft Windows XP with Service Pack 2).

2.3 *Procedure*

*2.3.1 Emotional Inducing Procedure*

All participants completed their group-specific task in the following order:

- 1) oning.tion has predictable effec they cted to "n of the taskinndition and DispenS type of functioning.tion has predictable effeconing.tion has predictable effec they cted to "n of the taskinndition and DispenS type of functioning.tion has predictable effeconing.tion has predictable effec they cted to "n of the taskinndition and DispenS type of functioning.tion has predictable effecBefore starting the task, participants were given a full verbal description and asked to sign a consent form. They then completed a computerised version of SAI.

2) Participants were then presented with the six Calibration images for 10s each at 500ms intervals. This was the same for negative and positive emotional conditions. After this, participants were presented with twenty images – negative and positive according to the assigned group. Each image stayed on screen for 2s, presented at 500ms intervals.

*2.3.2 Main experimental task*

3) Participants were presented with the following text to frame the scenario:

‘*You are a soldier working in a remote control room. You must monitor the images that are being streamed from a camera mounted on a soldier engaged in fierce fighting. The images coming from the battlefield are jumpy and blurred because of a bad connection. The enemy is trying to interfere with, or break, the connection, which is why sometimes you might see images that are not from the original camera. Your task is to monitor the camera images from the soldier and gather as much information about the situation as you can. Military Headquarters will at times ask you to confirm or deny information*. “

4) The task started and participants were required to monitor the scenario.

5) At six points the scenario was interrupted and eight QASA probes were presented to participants – 48 probes in total. 24 of the 48 probes were false (signal absent) and the ratio of false to true probes was 50/50. In each of the six blocks of statements there were 4 statements that were true and the remaining 4 that were false. Each QASA probe showed a content relevant photo followed by a true or false statement presented on the screen. Example statements are: ‘*There is a burnt tank behind you’, ‘One of your team has been killed*’. Participants were required to verify the veracity of the statements by surveying the developing ‘scenario’. A typical false statement would be “One of your team mates was wounded or killed” when no such event had happened.

Participants responded by pressing true or false via the keyboard: left arrow key for False, right arrow key for True – there was no time limit for responding. Participants were not informed about the likelihood of encountering true versus false statements but they were made aware that the information they were required to report to the Military Headquarters could be *denied* (see the last sentence on the text to frame the scenario – point 3 above).

6) At the end of the scenario, participants again completed the SAI inventory.

3. Results

*3.1 Control Measures*

A mixed-groups factorial ANOVA with pre- and post-test state anxiety scores as the within subject factor and positive and negative conditions as the between subjects factor (alpha = 0.05) was performed to examine the effects of positive and negative image sets in participants’ state anxiety. Space spaces space  
There was an interaction between pre- and post-test scores and positive and negative emotional conditions F(24.96)= 576, MSE= 23.1, p < 0.001. Table 3 shows the means and variance for positive and negative conditions for pre- and post-test anxiety scores. As expected, the negative images set led to an increase in state anxiety from pre- to post-test and the reverse was observed for the positive images.

Table 3. *Means for anxiety scores.* Mean normative and standard deviation (sd) scores are given for positive and negative conditions, before and after the task completion. The scores show that emotional stimuli increased anxiety for the negative condition (by around 9 points) and decreasing it for the positive condition (by about 4 points). Also, it can be seen that participants’ anxiety scores are close to even before the task starts.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  | Anxiety | |  |
|  |  | *Pre-Test* | *Post- Test* | *Average* |
| Condition | *Positive (mean/sd)* | 50.2/*6.92* | 46.8/*7.32* | *48.4* |
| *Negative (mean/sd)* | 51.13/*9.36* | 60.13/*8.45* | *55.63* |
|  | *Average* | *50.67* | *53.47* |  |

*3.2 Experimental Measures*

The mean Sensitivity and Bias scores for the two affect-conditions are shown in Figure 2. Using Boxplots, one outlier was detected in the negative condition. The outlier was replaced with the value closest to the outlier, which is a method known as “Winsorizing” (Tukey, 1962). An independent-samples t-test was conducted to compare Sensitivity for negative and positive emotional conditions. There was a significant effect of emotional condition on Sensitivity scores for positive (M = 48.75, SD = 21.23) and negative emotional conditions (M = 11.59, SD = 28.40) conditions; t(28) = 4.06, p < 0.001. These results suggest that emotional condition does have an effect on Sensitivity. Specifically, our results suggest that positive emotional condition leads to significant improvements on Sensitivity scores when compared to negative emotional condition.

A further independent-samples t-test was conducted to compare Bias for negative and positive emotional conditions. There was a significant effect of emotional condition on Bias scores for positive (M = -20.27, SD = 11.82) and negative emotional conditions (M = 10.33, SD = 6.61) conditions; t(28) = -8.75, p < 0.001. To support these results, a further independent-samples t-test was conducted to compare criterion for negative and positive emotional conditions (please see section 2.2.3 above, last paragraph, for further details). There was a significant effect of emotional condition on the criterion scores for positive (M = -0.37, SD = 0.16) and negative (M = 0.40, SD = 0.09) emotional conditions; t(28) = -16.39, p < 0.001. These results suggest that emotional condition does have an effect on Bias. Specifically, our results suggest that positive emotional condition leads to significant negative shift of the Bias scores in the positive condition relative to negative emotional condition.

Figure 2. *The mean Sensitivity and Bias scores for the two emotional conditions.* Error bars set at 95% confidence interval. Scores are rescaled from standard SDT scores so that they run from -100 to +100. For Sensitivity, -100 means participants consistently classify information incorrectly, 0 means they perform at chance, and +100 means they consistently classify information correctly. For Bias, -100 means participants accept all information as true (whether it is actually true or not), 0 means they have no bias towards accepting or rejecting information, and +100 means they reject all information as false. Mean differences on the measures of Sensitivity are significantly different between positive and negative emotional conditions. Mean differences on the measures of Bias are also significantly different between positive and negative emotional conditions.

To examine the relationship between Bias and Sensitivity, the Sensitivity scores were plotted against the Bias scores for each affect condition (Figure 3). A least-squares procedure was used to fit curves to the data, with a quadratic function providing the best fit. The model was a significant fit of the data in the negative (R2 = 0.48; F(2,12) = 5.60, *p* = 0.02) and positive (R2 = 0.78; F(2,12) = 21.23, *p* = 0.000001) conditions.



Figure 3. *Emotional Conditions and Correlation of Sensitivity and Bias.* Sensitivity scores plotted against Bias scores for the positive and negative emotional conditions. Linear (solid line) and quadratic (broken line) least-squares line fits are shown. Mean 95% confidence intervals are shown for the quadratic fits.

4. Discussion

In line with previous studies (e.g. Patton, 2014; Wilson et al., 2016), we found that task performance deteriorated in the negative emotional condition, but, we found further that the positive emotional condition actually improved performance. Previous research indicates that negative picture stimuli are processed more fully than neutral stimuli (Helton, Kern, & Walker, 2009) and are remembered with greater accuracy than both neutral and positive stimuli (Kern, Libkuman, Otani, & Holmes, 2005). Our results suggest negative picture stimuli consume bottom-up attentional resources to a greater degree causing a larger interference; a finding also reported by other studies (e.g. Ossowski et al., 2011). Additionally, the movement of Bias towards the positive spectrum in the negative emotional condition indicates that participants have become more cautious, supporting the conclusion that negative stimuli can increase behavior that relies on inhibition (Robinson et al., 2013; Wilson et al., 2015).

The self-reported scores of anxiety using the SAI inventory were elevated after the negative condition, whereas they were reduced after the positive condition. High arousal in itself, however, cannot explain the reduced performance in the negative condition. On the contrary, increased arousal has often been linked with an increase in resource capacity (Matthews et al., 2010) and is positively correlated with performance (Helton et al., 2009). A recent study found support for the view that arousal quality of picture stimuli matters more for performance than valence, concluding that increased arousal may result in improved performance regardless of their increased disruptive effect (Flood, Näswall & Helton 20015). Hence, looking at the arousal scores alone, we would expect improved performance in the negative and decreased performance in the positive condition. We argue, therefore, that the reduced performance effects found here in the negative condition are due to its effects on the bottom-up processes of attention and the interference with the top-down attentional processes, rather than emotionally-induced arousal levels.

Unlike the negative stimuli, positive stimuli led to improved performance in the task. Again, under-arousal or boredom cannot explain the results for the positive picture condition since these are attributes usually associated with under-performance (Helton et al., 2009). We suggest that the processing of positive stimuli relies on the top-down attentional controls to a higher degree than does the processing of negative stimuli, therefore causing less interference on a task that relies on top-down processes of attention – the stimuli can be more easily ignored. Other research (Shiv, Loewenstein, Bechara, Damasio, & Damasio, 2005) has produced similar results, negative emotions lead people to become more conservative with their choices whereas positive emotions promote a more exploratory behaviour. In a wide ranging review Isen (2001) concludes that in “*most circumstances, positive affect enhances problem solving and decision making, leading to cognitive processing that is not only flexible, innovative, and creative, but also thorough and efficient*”. The improved performance in the positive condition suggest that the top-down control of attention by a distributed fronto-parietal network that acts upon early representations in sensory cortex may actually benefit from modulation by task-irrelevant positive emotional stimuli.

A further finding in this study has been the differing relationship between Bias and Sensitivity in different emotional states. The plot of the negative emotional condition displays a pronounced C-shaped relationship (Figure 3), indicating that high positive Bias is associated with very good *or very poor* Sensitivity. This suggests that a positive Bias could lead to good Sensitivity *if* the right information is focused on, but focusing on the wrong information would produce very poor Sensitivity.

The pattern of data in the positive affect condition was similar, but not the same. As Bias shifts towards the negative end of the scale the level of Sensitivity increases and then plateaus. Thus, high negative Bias is associated with high Sensitivity, but there is a point where further increases in negative Bias do not lead to concomitant increases in Sensitivity. However, few participants had very negative Bias so this conclusion should be treated with caution. It is possible that beyond a certain point the individuals are unable to process any more information, so Sensitivity does not get any better. This is consistent with a large body of research that suggests individuals can only process a limited amount of information (Kahneman, 1973; Vogel & Machizawa, 2004; Szameitat et al., 2016).

The present study also has practical implications. In some jobs people are required to synthesise information while simultaneously being exposed to irrelevant negative emotional stimuli, for example during search and rescue operations in war zones or during humanitarian interventions in natural disasters. Our findings suggest that their performance may suffer because of exposure to highly negative emotional stimuli. As such, the logical conclusion that our study leads to is that people who are less sensitive to exposure to emotionally negative stimuli will perform better in such situations. A future study taking into account individual differences to emotional sensitivity may look more directly into this possibility. Finally, there are recent reports that neurofeedback training can help mitigate some of the negative effects of negative emotional stimuli (Bruhl et al., 2014). Such training methods could be considered when the deployment of people in risky situations is warranted. Such training may help mitigate some of the unwanted effects of negative emotional stimuli. Other researchers have made similar suggestions for mindfulness training (Ossowski et al., 2011).

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