School of Population Health

Examining the Role of Attentional Bias in the Context of Negative and Positive Content in Real-World and Laboratory-Based Settings

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Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made. This thesis contains no material which has been accepted for the award of any other degree or diploma in any university. The research presented and reported in this thesis was conducted in accordance with the National Health and Medical Research Council National Statement on Ethical Conduct in Human Research (2007) – updated March 2014. The proposed research studies received human research ethics approval from the Curtin University Human Research Ethics Committee (EC00262), Approval Numbers HRE2017-0060 and HRE2021-0136.

Date: 24/06/2022 Signature:

Acknowledgement of Country

We acknowledge that Curtin University works across hundreds of traditional lands and custodial groups in Australia, and with First Nations people around the globe. We wish to pay our deepest respects to their ancestors and members of their communities, past, present, and to their emerging leaders. Our passion and commitment to work with all Australians and peoples from across the world, including our First Nations peoples are at the core of the work we do, reflective of our institutions' values and commitment to our role as leaders in the Reconciliation space in Australia.

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Abstract

Attentional bias towards negative information and associated fears can be adaptive in specific contexts where they facilitate the avoidance of harm, but they have also been implicated in psychopathology. Conversely, attentional bias towards positive information may be associated with beneficial psychological and behavioural outcomes. Substantial research has examined attentional bias in the context of negative information and negative emotion, but less is known about attentional bias towards positive information and associated positive emotion. Similarly, research has examined the potential neural underpinnings of biased attention towards negative information and emotional effects relating to attenuating reactivity towards negative content, often via non-invasive forms of neurostimulation such as transcranial direct current stimulation (tDCS). However, no studies have examined how changes in cortical activity in neural areas implicated in the regulation of both attention and emotion influence attentional bias in the context of positive information. Therefore, the current research examined these attentional and emotional processes in the context of both negative and positive information. These processes were examined in both an applied setting relating to attention bias for positive (protective) and negative information relevant to viral contamination (the COVID-19 pandemic) and a second laboratory-based study examining specific effects of altering cortical activity on attentional bias and emotional reactivity for positive and negative information.

Study 1 examined attentional and emotional processes in the context of a highly relevant and current threat, the COVID-19 pandemic. Specifically, the aim of this study was to examine whether contamination fear predicts engagement in mitigation behaviours specific to contamination risk, and whether this relationship is moderated by attentional bias towards (negative) contamination-related information and/or attentional bias towards (positive) mitigation-related information. For this online correlational study, a final sample of 265 participants was obtained from universities and the general public (M_{age} = 21.00, *SD* = 5.10; 69.4% female). Questionnaires were used to measure participants' levels of contamination fear and engagement in contamination-related mitigation behaviours. Attentional bias was measured using a dot-probe task in which neutral words were paired with either contamination-related words (e.g., "virus") or contamination mitigation-related words (e.g., "soap"). Greater contamination fear was associated with increased engagement in mitigation behaviour. No relationship was found between either attention bias towards

mitigation-related or contamination-related information and contamination fear. Similarly, neither measure of attentional bias had a moderating effect on the relationship between contamination fear and mitigation behaviour.

Study 2 examined the effects of tDCS on attentional bias towards both negative and positive information, and its effects on emotional reactivity in response to both negative and positive content. Specifically, the aim of this study was to examine whether anodal tDCS targeting the left dorsolateral prefrontal cortex would lead to decreased attentional bias towards negative information and/or decreased negative reactivity in response to negative content. Additionally, this study aimed to examine the effect of tDCS on patterns of attention towards positive information and positive emotional reactivity in response to positive content. For this single-blind experimental study, 101 participants were recruited through Curtin University and social media advertising (M_{age} = 22.57, SD = 5.60; 66.33% female). Participants were allocated to either the active or sham tDCS condition. Attentional bias was measured using an eye-tracking task involving negative-neutral and positive-neutral image pairs followed by an emotional reactivity assessment task involving negative and positive video content. Results showed no evidence that tDCS influenced attentional patterns towards either type of information, nor was there evidence that tDCS influenced self-reported anxious mood or physiological arousal. However, participants in the active tDCS condition did report higher positive mood in response to both the positive and negative videos compared to those in the sham condition. Participants in the active tDCS condition also showed higher levels of self-reported arousal in response to positive content and lower arousal in response to negative content, with those in the sham tDCS condition showing the reverse pattern of effects. However, this result only met conventional significance and not Bonferroni-corrected significance.

The results of Study 1 suggest that specific fears may lead to greater engagement in adaptive mitigation behaviour, such as those relevant to contamination risk, but they did not support the role of attentional bias towards either positive or negative content in this relationship. The results of Study 2 suggest that tDCS to prefrontal areas of the cortex may have positive effects on mood and goal-directed emotional regulation. This may have implications for potential future psychological interventions. Unlike other prior studies, these results did not replicate the effect of tDCS on biased attention. It may be important for future studies to examine attentional bias towards (negative) contamination-related and (positive) mitigation-related information in the context of exposure to contamination threat. It would also be valuable for future research to examine tDCS and biased attention in clinical samples, or those with elevated trait anxiety or depressive symptoms.

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Research shows that people tend to be particularly vigilant for stimuli that are emotionally arousing, such as those that evoke fear (Öhman et al., 2012; Vogt et al., 2011). This tendency to be hypervigilant to specific types of information is known as attentional bias. Attentional biases that favour negative information can be adaptive in contexts where they facilitate the avoidance of environmental harms (Mallan et al., 2013; Öhman et al., 2012). However, attentional bias towards threat can also be maladaptive, as evidence suggests that it may have a causal or maintaining role in anxiety disorders (Barry et al., 2015; Notebaert et al., 2016; Thoern et al., 2016).

Given its implication in anxious psychopathology, attentional bias has primarily been examined in relation to negative or threatening stimuli. It may be equally important, however, to examine attentional bias towards information that is perceived to be positive or protective. Research has suggested that attentional biases towards information that represents mitigation of relevant danger may be implicated in the avoidance of such danger, such as in the context of contamination risk (Vogt et al., 2011). More broadly, other studies have shown that attentional bias towards emotionally positive information may also be associated with beneficial outcomes such as greater resilience to stress (Thoern et al., 2016) and increased positive affectivity (Grafton et al., 2012). Considerably less is known about attentional bias in the context of positive/protective information compared to negative information, however, and this is particularly the case in research that has sought to understand the neurocognitive processes that underlie attentional bias and associated emotional processes.

Studies examining attentional bias have used methods such as eye-tracking and response time tasks to assess individuals' patterns of attention towards certain categories of information and how these patterns may be associated with emotional and cognitive processes (Chen et al., 2017; Thoern et al., 2016). There is also an increasing body of research that implicates various neural processes in attention and emotion. Current research is increasingly employing methods of non-invasive neurostimulation, such as transcranial direct current stimulation (tDCS; Chen et al., 2017; Clarke, Browning, et al., 2014; Clarke, Van Bockstaele, et al., 2020; Ironside et al., 2019). These studies have examined how the temporary augmentation of neural activity in specific regions of the brain implicated in emotional regulation, such as the left dorsolateral prefrontal cortex (DLPFC), influence both emotion and associated patterns of attentional bias. Some research has suggested that potentiating neural activity in specific areas may facilitate a reduction in attentional bias towards negative information and attenuate negative emotions in response to negative content (Brunoni et al., 2014; Chen et al., 2017; Heeren et al., 2017; Ironside et al., 2016, 2019). However, no research to our knowledge has examined the effects of neural stimulation on attentional bias towards positive information and positive emotion.

The two studies reported in the present dissertation both focus on aspects of attentional bias spanning negative/threatening information and positive/protective information, and examine relationships with related emotional and behavioural processes. Study 2, a laboratory-based project examining the interactive effects of neurostimulation on cognitive biases and emotional processes, was originally conceived at the commencement of 2020. However, due to the ensuing onset of the COVID-19 pandemic, the laboratory-based project was not feasible. However, the pandemic provided a unique opportunity to examine patterns of attentional bias towards different classes of stimulus in the context of a highly relevant and legitimate current threat. Study 1 therefore focussed on the adaptive nature of fear and attentional biases towards positive/protective stimuli versus negative/threatening stimuli in the context of the COVID-19 pandemic, as these processes had not yet been explored in this specific context. This study examined the role of these cognitive processes and how they may be associated with patterns of adaptive behaviour, and whether attentional biases towards threat-related and/or positive protection-related information had an interacting effect on these processes. The focus on assessing attentional bias for more positive/protective information represented a key extension of this research that many past studies have not examined.

The subsequent relaxation of physical distancing rules in 2021 provided the opportunity to revisit the original laboratory-based study design, and I was able to extend upon Study 1 by implementing a laboratory-based project in Study 2. The online nature of Study 1 presented some methodological limitations, such as our measure of attentional bias being restricted to a dot-probe task which is known to have low levels of internal reliability (Chapman et al., 2017; Schmukle, 2005). Additionally, we were unable to examine potential underlying neural processes of interest that are thought to impact both attention and emotion. Therefore, Study 2 involved an eye-tracking task to measure patterns of biased attention, as it is a more direct method of indexing attentional bias compared to the dot-probe task (Skinner et al., 2017). This study also involved tDCS targeting the left DLPFC, which allowed us to examine the potential influence of neural processes underpinning attentional patterns and associated emotional reactivity in the context of both negative and positive content. Specifically, we examined whether tDCS would lead to decreased attentional bias to negative information and/or decreased negative reactivity in response to negative content. Additionally, we examined the extent to which tDCS would affect patterns of attention towards positive information and positive reactivity in response to positive content, as this has not yet been examined in the literature. The following two studies have been written as stand-alone papers, with specific backgrounds relevant to the focus of each provided in their respective introduction sections.

Study 1: Investigating the Role of Contamination Fear and Attentional Bias on Mitigation Behaviours During the COVID-19 Pandemic

Psychological research commonly examines fear from a pathological perspective. This tends to be the case in the context of general fear in anxiety disorders and also with contamination concerns in the context of obsessive-compulsive disorders (OCD; Abramowitz et al., 2009; Armstrong et al., 2012; Eysenck et al., 2007). However, fear can be a highly adaptive response in situations where avoidance of danger is necessary for one's health or survival (Öhman et al., 2012). People have a tendency to be vigilant for stimuli that represent innate threats, such as snakes or angry faces, and this highlights the potentially adaptive value of fear and associated cognitive processes (Hoehl et al., 2017; Mallan et al., 2013; Öhman et al., 2012). Such innate fears appear to have an evolutionary advantage in that being attuned to dangerous stimuli in the environment can lead to their avoidance, thus mitigating the risk of harm (Öhman et al., 2012; Vogt et al., 2011). This tendency to be hypervigilant to information that is perceived to be dangerous is known as attentional bias towards threat (Armstrong et al., 2012).

Another example of a common fear that may confer some evolutionary advantage is that of contamination (Armstrong et al., 2012). Disgust and fear in response to sources of potential contamination confer an evolutionary advantage, allowing us to avoid disease, suggesting that a non-clinical level of contamination fear may play a functional role in the avoidance of disease (Curtis et al., 2011; Verwoerd et al., 2013). Contamination fear may be particularly acute during certain situations characterised by higher risk or visibility of contamination risk (Wheaton et al., 2012), such as pandemics like the current coronavirus (COVID-19) crisis. Fear of virus contamination may indeed be beneficial if it motivates danger mitigation behaviours such as handwashing, which is of great importance during the COVID-19 pandemic. The potential benefits of both contamination and attentional bias towards threat are particularly relevant to the COVID-19 pandemic in which mitigation of infection risk is highly adaptive to individuals and communities.

The COVID-19 crisis is worldwide and having continuing effects on individuals and entire populations with social behaviour having changed dramatically in ways designed to minimise transmission of the disease (Amin, 2020; Boseley & Landis-Hanley, 2020). As this pandemic is very recent and still ongoing, there is little research on the psychological effects it may be having on individuals. Some reports show increased access to helplines and online mental health services, which suggests that the pandemic may be having adverse effects on mental health (Hayne, 2020; Henriques-Gomes, 2020). However, the seriousness of COVID-19 and the current emphasis on mitigation behaviours such as handwashing and physical distancing may be leading to higher levels of anxiety in the general public, similar to what occurred during the 2009 H1N1, or “swine flu”, pandemic (Wheaton et al., 2012). More specifically, an increase in contamination fear may be occurring in the general public during this current pandemic, and its manifestation may share some similarities with symptoms of contamination-specific OCD (Wheaton et al., 2012). It is not yet known whether this potential increase in contamination fear plays an adaptive role in decreasing the spread and risk of COVID-19, and if so, what factors may contribute to this. In relation to swine flu, some cross-sectional studies have found that people with greater contamination-related anxiety were more likely to engage in preventative behaviours (Bults et al., 2011; Kim et al., 2014; Rubin et al., 2009). This research provides evidence to suggest that contamination fear may predict engagement in mitigation behaviours in response to threats such as the COVID-19 pandemic.

Other research has drawn contrasting conclusions regarding the role of anxiety in contributing to mitigation behaviour. Specifically, a number of studies have shown that trait anxiety has been associated with lower levels of preventative behaviours, such as health screening and preparing for natural disasters in high-risk locations (Mishra & Suar, 2012; Notebaert et al., 2016). It is not completely clear why anxiety may lead to impaired engagement in such mitigation behaviour. One possibility is that the combination of elevated anxiety and attentional bias towards threat may lead to the adoption of more emotion-based coping strategies or avoidance of perceived danger, as opposed to adaptive problem-solving behaviours (Mishra & Suar, 2012; Notebaert et al., 2016). This is in contrast to the aforementioned research indicating a positive relationship between contamination fear and relevant preventative behaviours. Differences in these findings may be due to the individual’s perceived level of control over a situation, with people being more likely to engage in a behaviour if they believe it can affect an outcome (Mishra & Suar, 2012; Notebaert et al., 2016). So, this may also explain why higher contamination anxiety appears to predict engagement in mitigation behaviours during situations such as the H1N1 pandemic, as there are clearly defined behaviours that can help prevent virus contamination, such as handwashing and use of disinfectants (Rubin et al., 2009; Wheaton et al., 2012). It is also worth noting that the studies in which anxiety was found to predict less engagement in mitigation behaviours measured general anxiety as opposed to contamination fear specifically, which may partially account for some discrepancies in the literature (Notebaert et al., 2016).

Evidence also suggests that patterns of information processing that favour more threatening information in the environment may influence mitigation behaviour. Specifically, attentional biases towards contamination-related threat may be implicated in contamination-related mitigation behaviour. Findings have shown that people tend to exhibit attentional biases towards stimuli and events that are emotionally arousing, such as those that evoke fear (Vogt et al., 2011). These biases have been consistently shown in people with anxiety disorders, including post-traumatic stress disorder and contamination-specific OCD (Armstrong et al., 2012; Ólafsson et al., 2019). Substantial evidence shows that anxious people have an attentional bias towards threatening stimuli and are especially attentive towards threats that are relevant to their specific domain of concern (Pergamin-Hight et al., 2015). For example, those with social anxiety disorder tend to be biased towards cues that represent social failure, and those with posttraumatic stress disorder (PTSD) tend to be biased towards trauma-related information (Pergamin-Hight et al., 2015).

Attentional biases towards threat also appear to have a causal or maintaining role in anxious mood which, according to Notebaert et al. (2016) may be a contributing factor as to why attentional bias towards threat has been mostly examined in the context of being a maladaptive process. However, attentional biases may play an adaptive role in mitigating legitimate threats such as COVID-19. Attentional bias in contamination fear has typically been examined in the context of OCD as it is one of the most common fears associated with the disorder (Armstrong et al., 2012). Sources of perceived or actual contamination are considered threatening to people with contamination OCD, and studies have provided evidence to show that these individuals tend to be vigilant to such threats (Armstrong et al., 2012; Summerfeldt & Endler, 1998). Attentional biases may contribute to and maintain the compulsive behaviours associated with OCD, such as cleaning rituals and avoidance of the feared stimuli (Armstrong et al., 2012; Cisler & Olatunji, 2010; Rouel & Smith, 2018). This suggests that attentional biases may have adaptive value, in that sources of contamination or infection could be identified, and action taken to avoid or mitigate the danger posed by the threat as a result. In OCD however, compulsive avoidance of perceived threat often causes significant distress and impairment for the individual, so in these cases, attentional bias towards threat and consequent mitigation behaviours would not be considered adaptive (Armstrong et al., 2012). Specifically, mitigation behaviours may be considered maladaptive in situations where they are disproportionate or excessive in relation to the relevant threat, such as time-consuming cleaning rituals exhibited by an individual with contamination OCD (Abramowitz et al., 2009). Conversely, mitigation behaviours that are proportionate and appropriate in relation to the relevant threat may therefore be considered adaptive, such as hygiene behaviours designed to reduce the spread of COVID-19 amongst the general population. Thus, as contamination fear has not been extensively examined in non-clinical populations, further research is needed in order to investigate these biases, particularly in the context of a pandemic where avoidance of contamination is highly adaptive.

Some research has suggested that in addition to its contribution to higher levels of anxiety, greater attentional bias towards threat may also have both a negative and positive effect upon the engagement in mitigation behaviours. A novel study by Notebaert et al. (2016) examined the relationship between trait anxiety, attentional bias towards threatening stimuli, and preparatory behaviours in relation to bushfires, a legitimate threat for the population examined in the study. This study showed that participants with higher trait anxiety were found to have lower engagement in preparatory behaviours, and attentional bias towards threat increased the strength of this relationship. The results of this study support prior research that implicates higher levels of trait anxiety in the impairment of danger mitigation behaviours. Differences in attentional bias could therefore be involved in the contradictory findings in the previously mentioned literature which showed that higher levels of contamination anxiety did predict engagement in mitigation behaviours. Interestingly, in the same study by Notebaert et al. (2016), attentional bias towards threat also moderated the negative correlation between trait anxiety and danger preparedness in a way that led to greater preparedness in individuals with lower trait anxiety. So, for individuals with lower trait anxiety, attentional bias towards threat led to heightened preparatory behaviour but the opposite was found for those high in trait anxiety. This suggests that attentional bias to threat may have a beneficial effect on engagement in mitigation behaviours, but only in certain individuals. Again, however, this study examines the broad construct of trait anxiety and it is therefore unclear whether similar effects would be observed in the context of more specific contamination fear in the context of the current pandemic.

Another aspect of attentional bias that may have direct relevance to the COVID-19 situation is attentional bias towards stimuli that represent mitigation of threat-relevant objects or events. Evidence suggests that during exposure to a threat, attentional processes tend to favour not only sources of the threat, but also information that can facilitate the mitigation of that specific threat (Vogt et al., 2017). This means that stimuli that may not normally be perceived as positive may become prioritised by attentional processes if they represent a means by which a current threat can be mitigated (Vogt et al., 2017). Attentional biases can also be influenced by an individual’s emotional state, such as fear (Ford et al., 2010), or current goals, such as the avoidance of a threat (Crusius & Lange, 2014). For example, negative emotions associated with contamination risk may provide the goal of avoiding sources of contamination, via vigilance towards both sources of contamination and otherwise neutral stimuli that are rendered positive via their capacity to mitigate against contamination, such as soap. Like fear, the experience of disgust in response to contamination-relevant stimuli or situations plays an adaptive evolutionary role in that it provides motivation to avoid objects or situations that present a potentially harmful contamination risk (Curtis et al., 2011; Vogt et al., 2011). Vogt et al. (2011) examined attentional bias in the context of contamination risk and disgust to assess the potential presence of attentional bias towards both contamination-related stimuli and stimuli related to the mitigation of contamination threat. Half of the participants in this study were presented with ten objects designed to elicit disgust, such as a toilet brush covered in coffee powder, and they were asked to interact with the objects and imagine they are actually dirty. The other half of the participants were placed in a control condition and were presented with ten neutral objects instead of disgusting ones, such as a roll of tape. Each participant then immediately rated their levels of disgust and was offered the opportunity to wash their hands. After the disgust-inducing procedure, attentional bias was measured using the dot-probe task as adapted from Macleod et al. (1986). The stimuli used in this task were photographs classified as either disgust-inducing, neutral, or representative of cleanliness. Results of this study showed that all participants displayed an attentional bias towards the disgust-related stimuli, but only those in the condition that involved the induction of disgust showed a bias towards stimuli that represented cleanliness.

The findings of Vogt et al. (2011) provide an interesting precedent for research in the area of the COVID-19 pandemic, as it suggests that potential contamination risk may lead to attentional biases towards stimuli that represent both the contamination risk itself but also to stimuli that represent risk mitigation. This is relevant to the COVID-19 pandemic in that it represents a legitimate contamination risk to the public, and if people are attending to the threat itself, they may also be attending to stimuli related to the mitigation of contamination, such as soap or hand sanitiser. As to whether such attentional biases may promote mitigation behaviour in response to COVID-19, Vogt et al. (2011) also found that several participants in the disgust condition washed their hands when given the opportunity to do so, which may suggest an association between attentional bias and motivation to engage in actual mitigation behaviour. It is worth noting, however, that this study included exclusively female participants as they have been shown to have a higher propensity towards disgust compared to males (Druschel & Sherman, 1999). Therefore, these factors may affect the generalisability of these findings in the context of contamination fear in the general population.

For the current study, our aim was to examine whether contamination fear predicts engagement in mitigation behaviours specific to contamination risk, and whether this relationship is moderated by attentional bias towards threat-related stimuli and/or attentional bias towards mitigation-related stimuli. Specifically, we examined whether the relationship between contamination fear and mitigation-related behaviour (specifically hygiene behaviour) is stronger among those who attend more to signals of contamination threat and/or mitigation-related information. Though past research has shown that greater levels of anxiety may be associated with avoidance of mitigation behaviour, other studies have suggested that anxiety related to a specific concern may be associated with greater engagement in behaviours that mitigate that concern. Additionally, the results of the study by Notebaert et al. (2016) suggest that patterns of attentional bias towards threat-related information may have a moderating effect on the relationship between anxiety and adaptive behaviour, such that heightened vigilance towards threat may potentially lead to increased mitigation behaviour in those with lower anxiety, and decreased mitigation behaviour in those with higher anxiety. Therefore, we first assessed the hypothesis that contamination fear would positively predict engagement in mitigation behaviour. Secondly, we assessed the hypothesis that if there is a significant relationship between contamination fear and mitigation behaviour, this relationship would be moderated by either or both attentional bias towards contamination-related information and attentional bias towards mitigation-related information.

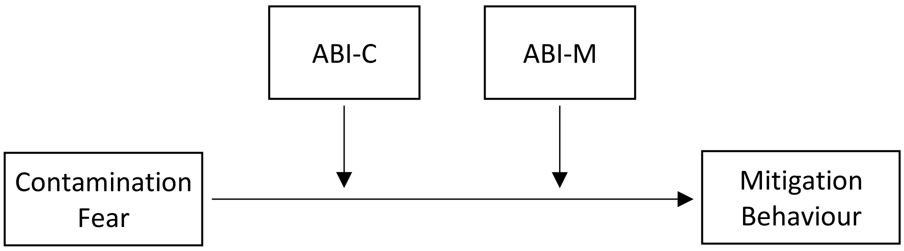
Method

Research Design

To address our research question, we conducted a cross-sectional correlational study. We administered self-report questionnaires to measure our predictor and criterion variables, which were contamination fear and engagement in contamination mitigation behaviours, respectively. We used cognitive assessments of attention to measure our two moderator variables, which were attentional bias towards contamination-related information and attentional bias towards mitigation-related information. Figure 1.1 illustrates the double moderation model.

Figure 1.1

An Illustration of the Double Moderation Model



Note. We examined the relationship between contamination fear and mitigation behaviours, and whether either or both attentional bias towards contamination-related information (ABI-C) and attentional bias towards mitigation-related information (ABI-M) moderate this relationship.

Participants

Previous research examining attentional bias and emotional measures showed that large effect sizes may have been expected in the current study (Cisler & Olatunji, 2010; Notebaert et al., 2016; Ólafsson et al., 2019). However, we calculated our required sample size based on a more conservative estimate of effect size given the low reliability of attentional bias measures (Chapman et al., 2017; Schmukle, 2005). In order to predict a small to medium effect ($f^2 = .05$), an a priori power analysis determined that our required sample size was 223, based on a power level of 0.8 and an alpha level of 0.05 (Faul et al., 2009). A convenience sample of 347 participants was recruited through Curtin University, the University of Western Australia, the University of Sydney, and the University of Sussex. There were no specific inclusion or exclusion criteria for the study and people were recruited through their respective university participant pools and via social media. Where relevant, university students were awarded participation points for completing the study, which fulfilled the partial course requirements. The sample was predominantly female (70.3%), and ages ranged from 17 to 58 years ($M = 20.75$, $SD = 4.79$). Ethical approval was obtained via the Curtin University Human Research Ethics Committee (ethics approval number HRE2017-0060) and all other institutions' respective ethics committees.

Measures

Depression Anxiety and Stress Scale 21

We employed the 21-item version of the Depression Anxiety and Stress Scale (DASS-21) to examine levels of general psychological distress within the sample and between institutions (Lovibond & Lovibond, 1995). It is a self-report questionnaire containing three seven-item Likert subscales that measure symptoms of depression, anxiety, and stress (Lovibond & Lovibond, 1995). Respondents are asked how often they experienced a particular symptom over the last week (e.g., "I found it hard to wind down"), with scale responses ranging from 0 (*Did not apply to me at all*) to 3 (*Applied to me very much, or most of the time*). Scores on each subscale are summed, resulting in a total score for each subscale. For the purposes of our study, we summed the DASS-21 scores for each of the three subscales to create an overall measure of psychological distress, with possible scores ranging from 0 to 63. The DASS-21 has consistently displayed good reliability and validity in general populations (Crawford et al., 2011; Oei et al., 2013). Internal consistency was high in our sample, with Cronbach's alpha levels for the depression, anxiety and stress subscales at .91, .86, and .87, respectively.

Padua Inventory (Contamination Fear Subscale)

We employed the Contamination Obsessions and Washing Compulsions subscale of the Padua Inventory (PI-COWC) to measure participants' levels of contamination fear (Burns et al., 1996). It is a 10-item Likert scale that measures the degree to which one relates to symptoms of contamination fear. For example, one item is "I find it difficult to touch an object when I know it has been touched by strangers or by certain people" (Burns et al., 1996). Scores range from 0 (*Not at all*) to 4 (*Very much*) and are summed, resulting in a total subscale score. Consistently high levels of reliability have been observed for this subscale (Rubio-Aparicio et al., 2020). Internal consistency was high in our sample (Cronbach's alpha = .92).

Hygiene Inventory

We employed the Hygiene Inventory (HI23) to measure participants' engagement in contamination mitigation behaviours (Stevenson et al., 2009). It is a 23-item Likert scale comprising five subscales that measure behaviours related to handwashing, food handling, household cleaning, clothing hygiene, and general hygiene (Stevenson et al., 2009). For example, participants are asked "Upon getting home, do you wash your hands?" (Stevenson et al., 2009). Scores on each item range from 0 to 4. Scores on all items are summed, resulting in a total score with higher scores representing greater engagement in hygiene behaviour. Adequate levels of construct validity and reliability have been observed for this scale in general population samples (Stevenson et al., 2009). Internal consistency was high in our sample (Cronbach's alpha = .81).

Dot-probe Task

For the attentional bias measure, we used a dot-probe task as adapted from Macleod et al. (1986). For the purpose of the current study, the task required stimulus word pairs of two types: contamination-relation vs neutral word pairs and mitigation-related vs neutral word pairs. To attain this, an initial list of 80 candidate neutral words, 53 words related to contamination and 42 words related to mitigation of contamination were rated by twelve independent judges. These candidate words were rated on their degree of relatedness to virus concerns (1 = *Highly related*, 5 = *Moderately related*, 9 = *Completely unrelated*). Words rated 5 or greater on this scale were then rated on their relatedness to either contamination risk or protection from contamination (1 = *Strongly related to risk*, 5 = *Related to both*, 9 = *Strongly related to protection*). Words rated most relevant to virus concerns, contamination, and protection were selected and paired with a neutral word (rated above 7 in terms of virus relatedness) equal in character length. This resulted in 24 contamination-neutral word pairs (e.g., “virus” vs “click”) and 24 mitigation-neutral word pairs (e.g., “soap” vs “ball”).

For each trial of the probe task, the participant was asked to initially focus on a cross (“X”) which was shown in the centre of the computer screen for 500ms. A word pair immediately followed and remained for 500ms. The words were vertically aligned and 25mm apart, with one word appearing above and the other below where the cross appeared. Once the words had disappeared, a single set of dots (i.e., the probe) in either vertical (“:”) or horizontal (“..”) alignment then immediately appeared where one of the words had been. The participants’ task was to determine the alignment of the dots as quickly and accurately as possible by pressing either 1 (the dots are vertical) or 2 (the dots are horizontal) on the keyboard. The next trial began 500ms after the participant responded. All text was black, and a white background was used. The target probe replaced the neutral word and the salient stimulus word (contamination-related or protection-related) with equal frequency on each trial. The order of word pairs, position of the words, probe location, and probe alignment were all randomised and counterbalanced to prevent order effects. An equal number of each probe type and word pair were presented in each block. The word pairs were randomised in blocks of 48 trials and we presented four blocks, resulting in a total of 192 trials for each participant.

To create an overall measure of attentional bias, we calculated an attentional bias index (ABI) score for each stimulus type by subtracting the average response time for probes appearing in the location of the contamination-related words from the average response time for probes appearing in the location of the neutral words. This process was repeated for the mitigation-related word pairings. This resulted in two index scores for each participant, with larger scores indicating a greater bias towards contamination-related information or mitigation-related information.

Procedure

Participants accessed the study by following a link to the study website. The website prompted the participant to download the Inquisit 5 software plugin (Millisecond Software, 2018), which allowed participants to complete the entire study on their home computers.

Participants were first provided with all relevant study information, and informed consent was obtained via clicking a "consent" button. If the participant did not wish to continue, they selected a "quit" button which terminated the study. Participants were required to measure a calibration line on their screen using a ruler to ensure consistency in display parameters across different screen sizes and resolutions. They then completed a demographics questionnaire, the DASS-21, PI-COWC, and HI23, followed by a practice dot-probe task and the actual dot-probe task. Participants also completed additional questionnaires and cognitive tasks as part of a broader project. Finally, participants were presented with debriefing information and services they could contact should the study have highlighted any issues they wished to follow up on. The study took approximately 30 minutes to complete.

Results

Data Preparation

Preparation of response time data from the probe task was in line with previous studies (Clarke, Van Bockstaele, et al., 2020). We first excluded individual dot-probe trials with incorrect responses, and responses falling below 200ms and above 2000ms. Individual response times falling outside 3 median absolute deviations (Leys et al., 2013) were also excluded. This resulted in the exclusion of 13.86% of trials in total. We also conducted split-half correlations to determine the reliability of each bias index measure. In line with other studies (Chapman et al., 2017; Schmukle, 2005), these reliability levels were observed to be low, ABI-Contamination: $r(327) = .36$, $p < .001$; ABI-Mitigation: $r(327) = .21$, $p < .001$.

To account for participants who may have been distracted or disinterested in the task, we excluded cases who correctly identified probe alignment less than 70% of the time (Clarke, Van Bockstaele, et al., 2020). Thirteen cases (3.7%) were excluded on the basis of this criterion. A further seven participants (2.1%) were excluded from the remaining sample on the basis of reporting low fluency in English given the word-based nature of the study. Four participants recorded a high percentage of missing data (no response on the HI23 measure) but these cases were already excluded as part of the previous criteria. We then identified index score outliers by calculating the interquartile range (IQR) for both measures and excluding scores that fell above the 75th percentile or below the 25th percentile by 1.5 times the IQR (Walfish, 2006). From the remaining sample, we excluded a total of 62 index scores (19%). All exclusion criteria resulted in a total of 82 excluded participants (23% of the initial sample).

Mahalanobis distance calculations indicated no multivariate outliers, and assumptions of multicollinearity and homoscedasticity were met. Stem-and-leaf plots and histograms showed that data were normally distributed on all variables except the PI-COWC, which was slightly skewed. We did not consider this to be a problem, however, as we may expect some skewness given that the sample was not selected on the basis of elevated contamination fear and may show a slight "floor" effect.

Final Sample

Our final sample consisted of 265 participants. We compared the final sample and those excluded on the DASS-21 and HI23 measures to examine potential differences between the two groups. Independent samples *t* tests indicated no significant differences on the DASS-21, $t(344) = -0.75$, $p = .454$ or the HI23, $t(340) = 1.45$, $p = .149$. We also ran a chi-square test of contingencies to compare the groups on gender distribution. Again, there were no significant differences, $\chi^2(2, N = 342) = 2.64$, $p = .268$. Table 1.1 presents a breakdown of the final participant numbers, demographic information and overall DASS-21 scores by recruitment site.

Table 1.1

Participant Number, Gender, Mean Age, and DASS-21 Score by Institution and Total Sample

			Institution		
	Curtin	UWA	Sydney	Sussex	Total sample
Total participants					
N	77	56	91	41	265
% of total sample	29.1	21.1	34.3	15.5	100
Gender (%)					
Female	75.3	55.4	68.1	80.5	69.4
Male	24.7	42.9	29.7	19.5	29.4
Non-binary	0	1.8	2.2	0	1.1
Age (Years)					
M	21.3	21.4	20.1	21.8	21.0
SD	5.1	7.4	3.1	4.8	5.1
DASS-21 score					
M	22.2	19.4	20.5	25.3	21.5
SD	11.0	13.0	14.7	14.3	13.4

Note. Curtin = Curtin University; UWA = The University of Western Australia; Sydney = The University of Sydney; Sussex = The University of Sussex; DASS-21 = Depression Anxiety and Stress Scale 21.

Correlations Between Main Variables

To examine basic relationships between our predictor and outcome variables, we first ran a bivariate correlation analysis using IBM SPSS Statistics (Version 27). Analysis showed a statistically significant positive relationship between the PI-COWC and HI23 measures, which was of moderate strength. This indicated that higher levels of contamination fear were associated with increased levels of mitigation behaviour. We observed no other significant associations between variables (all *p*s > .108). Table 1.2 presents correlations between the PI-COWC, HI23, ABI-Contamination (ABI-C), and ABI-Mitigation (ABI-M) measures.

Table 1.2

Pearson Product-Moment Correlation Coefficients Between Main Variables

	PI-COWC	HI23	ABI-C
HI23	.42*		
ABI-C	-.10	.01	
ABI-M	.06	.03	.05

Note. PI-COWC = Contamination Obsessions and Washing Compulsions subscale of the Padua Inventory; HI23 = Hygiene Inventory; ABI-C = Attentional bias index score for contamination-related information; ABI-M = Attentional bias index score for mitigation-related information.

*$p < .001$.

Basic Attentional Bias Scores

We ran two one-sample *t* tests to examine whether participants' mean ABI-Contamination scores (*M* = -1.86, *SD* = 26.47) or ABI-Mitigation scores (*M* = 2.58, *SD* = 27.89) differed from zero. Results of both analyses showed that ABI scores did not significantly differ from zero, ABI-Contamination: *t*(264) = -1.15, *p* = .252, ABI-Mitigation: *t*(264) = -1.51, *p* = .133, indicating that our participants did not display an overall attentional bias towards or away from either type of information.

Moderating Effects of Attentional Bias

To examine whether attentional bias towards contamination-related information and/or attentional bias towards mitigation-related information has a moderating effect on the relationship between contamination fear and mitigation behaviour, we ran a double moderation analysis using the SPSS macro PROCESS (Hayes, 2017). We included institution as a covariate to control for any potential differences between recruitment locations. Number of bootstrap samples was set at 5000 and confidence intervals were set at 95%.

The overall moderation model was significant, accounting for 18.6% of the variance in HI23 scores, $F(6, 258) = 9.83$, $p < .001$, $R^2 = .186$, Mean Squared Error (MSE) = 54.63. Table 1.3 presents the main effects and interaction effects of the analysis.

Table 1.3

Standardised Coefficients, Standard Errors, t *values,* p *values, and 95% Confidence Intervals (CIs) for the Moderated Regression*

	Coefficient	Standard error	*t*	*p*	95% CI	
					Lower	Upper
Covariate						
Institution	-0.117	0.407	-0.29	.774	-0.919	0.685
Main effects						
PI-COWC	0.371	0.050	7.44	<.001	0.273	0.469
ABI-C	0.025	0.031	0.81	.419	-0.036	0.085
ABI-M	0.027	0.029	0.94	.348	-0.030	0.085
Interaction effects						
PI-COWC * ABI-C	-0.001	0.002	-0.43	.667	-0.004	0.003
PI-COWC * ABI-M	-0.002	0.002	-1.13	.260	-0.005	0.001

Note. PI-COWC = Contamination Obsessions and Washing Compulsions subscale of the Padua Inventory; HI23 = Hygiene Inventory; ABI-C = Attentional bias index score for contamination-related information; ABI-M = Attentional bias index score for mitigation-related information.

These results show that higher PI-COWC scores predicted higher HI23 scores, which is consistent with our hypothesis that contamination fear would positively predict engagement in mitigation behaviour. We also hypothesised that the relationship between contamination fear and mitigation behaviour would be moderated by either or both attentional bias towards contamination-related information and attentional bias towards mitigation-related information, but this was not supported by the results. No interaction effects were observed, and there were no significant differences between institutions.

Discussion

The current study sought to examine whether greater levels of contamination fear would predict greater engagement in contamination-related mitigation behaviours in the current context of the COVID-19 pandemic. This was supported by our results which showed that contamination fear levels had a positive association with mitigation behaviour. Furthermore, our study examined whether either or both attentional bias towards contamination-related information and attentional bias towards mitigation-related information would moderate this relationship. The double moderation analysis did not support this hypothesis. Additionally, we observed that our measures of contamination fear and mitigation behaviour were not associated with either measure of attentional bias.

The support for our first hypothesis suggests that contamination fear may indeed be adaptive in contexts where hygiene behaviours are especially critical, such as during the current COVID-19 pandemic. This finding was in line with previous studies that examined contamination fear and hygiene behaviours during the 2009 swine flu pandemic (Bults et al., 2011; Kim et al., 2014; Wheaton et al., 2012). As highlighted by Notebaert et al. (2016), a large body of evidence has shown some contradictory results in that greater anxiety may have an inhibitory effect on the engagement in general danger mitigation behaviour, but perhaps more in situations where the individual does not believe that their behaviour will help mitigate a negative outcome. In situations where outcomes can be controlled, actions taken to mitigate potential threat are appropriate and belief in this control is related to higher engagement in these preparatory actions (Mishra & Suar, 2012; Notebaert et al., 2016). Our results may provide further evidence to suggest that differences in mitigation behaviour may depend on the specific situation and associated behaviours, and the level to which one believes such behaviours can be helpful. It may therefore be worthwhile to further examine this notion of perceived control in further research and, specifically, whether one's belief that mitigation behaviours can reduce the risk of contamination plays a role in their engagement in such behaviours.

Our finding that supports the positive relationship between contamination fear and mitigation behaviour may also be explained through the idea of the *behavioural immune system* (BIS), which is a set of mechanisms thought to help us avoid disease (Schaller, 2006). Schaller (2006) posited that the BIS provides an initial defence against infection, through the detection of situations that present a contamination risk and subsequent activation of specific negative emotions and cognitions when exposed to such situations. These negative responses, such as disgust and fear, motivate behaviours that result in the avoidance of the perceived threat. Schaller and Park (2011) highlight that reducing social interaction is one important way through which contamination can be avoided, as numerous diseases are spread via social contact. For example, we may experience disgust or fear if we encounter a person who appears to be infected, and we may avoid this person as a result (Schaller & Park, 2011). Additionally, contexts characterised by heightened contamination threat, such as pandemics, can lead to the increased salience of cues that represent potential contamination, which in turn could result in avoidance behaviours (Schaller & Park, 2011). In the context of the COVID-19 pandemic, this may mean that people are more likely to notice, and subsequently avoid, people who are coughing, for example. The BIS therefore appears to provide a framework for the positive association between contamination fear and mitigation behaviours observed in the current study and previous research (Bults et al., 2011; Kim et al., 2014; Wheaton et al., 2012). However, it is worth noting that the BIS emphasises avoidance-specific behaviours, such as social distancing (Schaller, 2006; Schaller & Park, 2011). Our study did not measure such behaviours specifically, so including these behaviours as a critical measure may be an important direction for future research.

The lack of evidence for the moderating effects of attentional biases in the current study may be due to multiple factors. We utilised a standard measure of average attentional bias (via a dot-probe task) which has been shown to have consistently low reliability (Chapman et al., 2017; Schmukle, 2005), and this may have impacted our results. It would therefore be relevant to corroborate the present absence of effects in relation to attentional bias via alternative attentional bias measures in a more controlled assessment format, such as a laboratory-based setting incorporating eye-tracking (Chapman et al., 2017; Skinner et al., 2017).

Another factor to consider in relation to our results is that the participants completed the study in what we would assume to be a comfortable environment, given that they participated using their personal computers. This means that our participants may not have been exposed to contamination-related cues in their immediate environment as they were most likely at home due to physical distancing rules at the time of completion (Boseley & Landis-Hanley, 2020). In their study that examined attentional biases in relation to contamination-related information and cleanliness-related information, Vogt et al. (2011) induced feelings of disgust by exposing participants to an acute stressor, such as a toilet brush covered in coffee powder. They also used contamination-related imagery in their version of the dot-probe task, as opposed to words which we utilised in the current study. These factors in combination may explain why we did not observe any correlational relationships or moderating effects in relation to our attentional bias measures, as we did not deliberately induce acute feelings of contamination-related fears or disgust, nor use imagery which may have had a greater emotional effect than words. It may therefore be worth repeating this study with the inclusion of an acute stressor as used in the Vogt et al.

(2011) study, to examine whether this would elicit similar patterns of attentional bias towards contamination-related information or mitigation-related information. In relation to this, it is also possible that attentional biases are indicative of an individual's current motivations (Vogt et al., 2020), such as the avoidance of contamination during situations high in contamination risk. Given that we did not include an acute stressor that may have otherwise elicited feelings of contamination-related fear, it is likely that participants were not experiencing acutely high levels of motivation for avoiding contamination. However, the current study did not include explicit measures of current motivation, particularly in relation to the COVID pandemic specifically. It may therefore be of value for future research to include a measure of state motivation in relation to contamination avoidance, as this may be associated with patterns of attentional bias and related mitigation behaviours. This could also be usefully examined in the context of a laboratory-based stressor that may elicit acute changes in motivation to engage in mitigation behaviour.

Some specific limitations of this study should be noted. One limitation pertains to the HI23 measure, in that it does not capture the breadth of hygiene behaviours that are especially relevant during pandemics. We judged this measure to be sufficient for our purposes, as it is a validated scale and contains items that are highly relevant to the current COVID-19 pandemic, such as those related to handwashing and general hygiene (Stevenson et al., 2009). However, other protective behaviours that have been enforced during the COVID-19 pandemic, such as physical distancing and use of facial masks (Amin, 2020; Boseley & Landis-Hanley, 2020), are not included in this measure. Further research in the context of COVID-19 may benefit from the creation of a scale that covers a broader spectrum of behaviours specific to the mitigation of disease risk during pandemics. Another limitation worth noting is that our results may not be fully generalisable to the greater population due to the sample characteristics and use of convenience sampling. Most of the sample was obtained through university participant pools and almost 70% of the final sample was female, with a mean age of 21 years. Therefore, we cannot conclude that similar results would be seen with older individuals or a sample more representative of the general population in terms of gender or educational status. We would therefore suggest that further research in this area be conducted using a random sample with a greater age range and more members of the general public.

In conclusion, the results of the current study suggest that contamination fear may indeed play a meaningful role in motivating contamination-specific mitigation behaviours, which are of great importance during the COVID-19 pandemic. Our findings contradict past studies that found a negative relationship between general anxiety and adaptive behaviours (Mishra & Suar, 2012; Notebaert et al., 2016), yet they corroborate studies that found a positive relationship between contamination-specific fear and mitigation behaviours (Bults et al., 2011; Kim et al., 2014; Wheaton et al., 2012). This may therefore indicate the importance of further examining specific fears as opposed to general anxieties in the context of adaptive behaviour. The implications of this finding may also extend to practical applications in the area of health psychology, as we may be able to promote adaptive hygiene behaviour by creating a sense of contamination-specific concern in the community. We did not observe any evidence that attentional biases play a role in this relationship between contamination fear and mitigation behaviour, suggesting that perhaps contamination fear alone motivates such behaviour. However, future research is needed to determine whether this is indeed the case, as methodological factors in the current study may explain the lack of evidence for the role of attentional biases in this context. Future studies may include the examination of attentional biases using different attentional measures or including an acute stressor designed to induce a stronger sense of contamination fear. Specifically, it would be beneficial to include laboratory-based measures and equipment which may provide a more reliable means of indexing attention and emotion. We anticipate that our study will help promote future research that investigates the cognitive and emotional processes that underlie engagement in adaptive behaviours, which, in the context of health crises such as the COVID-19 pandemic, are critical to the health and survival of individuals and entire communities.

Study 2: Examining the Behavioural Effects and Neural Underpinnings of Selective Attention and Emotional Reactivity to Negative and Positive Information

Research shows that people tend to be particularly vigilant for stimuli that are emotionally arousing and relevant to an individual's concerns (Öhman et al., 2012; Pergamin-Hight et al., 2015). This hypervigilance to specific types of information is known as attentional bias. Attentional vigilance towards threatening information, such as angry faces (Mallan et al., 2013), can be adaptive in contexts where it facilitates the avoidance of immediate environmental harms (Barry et al., 2015; Mallan et al., 2013; Öhman et al., 2012). However, evidence also suggests that attentional bias towards threat may have a causal or maintaining role in common psychological disorders (Barry et al., 2015; Pergamin-Hight et al., 2015; Thoern et al., 2016). Attentional bias to threat is particularly relevant in the context of anxiety, as those with anxiety disorders or heightened trait anxiety tend to be hypervigilant towards information that is perceived to be threatening, even if there is no immediate risk of harm (Barry et al., 2015; Clarke, Browning, et al., 2014; Thoern et al., 2016). This hypervigilance towards threat may also distract individuals from attending to more neutral or positive stimuli, thereby perpetuating anxiety (Bar-Haim et al., 2007; Barry et al., 2015; Cisler & Olatunji, 2010; Thoern et al., 2016). Due to these potential negative effects, a considerable body of literature has focused on examining attentional bias in the context of negative information and how such biases can be modified (Hakamata et al., 2010; Pool et al., 2016; Thoern et al., 2016). As a result of this, attentional bias in the context of positive information has been examined comparatively less (Thoern et al., 2016).

Though the body of literature in this area is comparatively small, there is some evidence to suggest that attentional bias towards information that is perceived to be positive may play a role in promoting positive psychological outcomes such as resilience (Feder et al., 2009; Thoern et al., 2016), lower levels of anxiety (Frewen et al., 2008), and greater positive affectivity (Grafton et al., 2012). In one such study, Grafton et al. (2012) examined the effects of attentional bias modification training on positive affectivity in response to receiving positive feedback. Participants in this study were trained to either attend to positive information or avoid positive information via an attentional probe task, followed by an anagram solving task where they were given positive feedback on their performance in order to elicit positive mood. The results of this study showed that those in the attend positive condition displayed increased attentional bias towards positive information post-training and reported significantly greater self-reported positive mood in response to the feedback, compared to those in the avoid positive condition.

Another study by Thoern et al. (2016) examined the relationship between attentional bias towards positive stimuli and self-reported stress resilience. The results of this study indicated a positive correlation between attentional bias towards happy faces and greater trait resilience. Additionally, attentional bias towards angry faces did not predict resilience, but it appeared to have a moderating effect on the relationship between attentional bias to happy faces and resilience. The nature of this moderating effect meant that attentional bias towards happy faces only predicted higher trait resilience in those who also displayed an attentional bias towards angry faces. The results of this study therefore support previous research suggesting that attentional bias towards positive information may promote better mental health outcomes, but this may only be the case for individuals who display attentional bias towards both positive and negative information.

Studies examining the relationships between emotion and attentional bias have tended to use response time tasks to assess individuals' patterns of attention towards certain categories of information and how these patterns may be associated with emotional and cognitive processes (Chen et al., 2017; Thoern et al., 2016). Initially created by Macleod et al. (1986), the dot-probe task infers attentional bias via individuals' reaction times to target probes that appear in a location previously occupied by either a salient (e.g., positive/negative) or a neutral stimulus presented simultaneously (Chapman et al., 2017). Though it is a widely-used paradigm, it has consistently displayed low levels of internal reliability which raises concerns over its validity (Chapman et al., 2017; Price et al., 2015; Schmukle, 2005). Eye-tracking is an alternative approach to measuring patterns of attentional bias by recording eye gaze to measure the amount of time an individual attends to a salient versus a competing neutral stimulus (Skinner et al., 2017). This method is now being increasingly implemented as it is a direct and potentially more internally consistent measure of attentional bias (Skinner et al., 2017).

Given the robust and causal association between biased attention for threat and anxiety, neurocognitive models of emotion have increasingly sought to integrate the understanding of underlying neural structure and function with such patterns of cognition. Initially established using neuroimaging, a substantial amount of research has sought to understand the neural regions potentially involved in the allocation of attention to threat and how these processes are associated with emotional regulation (Clarke et al., 2021; Sanchez et al., 2016). This has given rise to research that has sought to determine the causal role of such regions by incorporating experimental manipulation of implicated cortical regions via non-invasive neurostimulation. One such method of neurostimulation which is now being increasingly employed is transcranial direct current stimulation (tDCS; Chen et al., 2017; Clarke et al., 2021; Clarke, Sprlyan, et al., 2020; Clarke, Van Bockstaele, et al., 2020; Ironside et al., 2019; Vicario et al., 2019). Anodal tDCS is used to increase the excitability of targeted regions of the cerebral cortex via a mild electrical current, often ranging between one to two milliamps (Vicario et al., 2019). This potentiation of neuronal activity is believed to occur via depolarisation of the neural membrane, thus lowering the threshold for neuronal firing, while cathodal tDCS causes the opposite effect via hyperpolarisation of the neural membrane (Remue et al., 2016; Woods et al., 2016). Studies utilising tDCS have examined how this temporary augmentation of neural activity in specific regions of the brain implicated in emotional regulation, such as the left dorsolateral prefrontal cortex (DLPFC), influences both emotion and associated patterns of cognition, with a particular focus on attentional bias. Research has suggested that hyperactivity of the amygdala combined with hypoactivity of prefrontal areas (such as the left DLPFC) may underlie anxiety and associated biased attention towards threat (Bishop, 2007; Bishop et al., 2004, 2007). Thus, increasing activity of the left DLPFC may lead to decreased attentional bias towards negative information, as has been supported by several studies examining the effects of tDCS on attentional bias (Brunoni et al., 2014; Chen et al., 2017; Heeren et al., 2017; Ironside et al., 2016, 2016).

For example, Ironside et al. (2016) examined the effects of tDCS on patterns of biased attention in a nonclinical sample. In this study, participants received either anodal tDCS to the left DLPFC concurrently with cathodal tDCS to the right DLPFC, anodal tDCS to the left DLPFC alone, or sham tDCS. Attentional patterns were measured via a dot-probe task involving pairs of neutral-fearful facial expressions. Results showed that participants who received active tDCS had a reduced attentional bias to fearful faces compared to sham, though these results were only statistically significant for those who received stimulation to both the left and right DLPFC. Nonetheless, these findings provide support for the role of prefrontal areas in attentional processes. A similar pattern of results was also found by Heeren et al. (2017) who examined tDCS and attentional bias in a sample with social anxiety disorder. Attentional bias was measured with a dot-probe task involving pairs of neutral-disgusted facial expressions, and results showed that those who received anodal tDCS to the left DLPFC showed a reduced attentional bias towards disgusted facial expressions, compared to those in the sham condition. This study therefore also provides further evidence that stimulation to frontal areas such as the left DLPFC can reduce biased attention towards negative information.

A large body of literature has also examined the emotional effects of augmenting neural activity via tDCS. These studies have mostly aimed to determine whether potentiating neural activity in areas such as the left DLPFC can improve emotional resilience, commonly assessed via exposing participants to negative information and/or emotional stressors. Most studies have found that tDCS leads to less pronounced increases in negative emotion in response to such situations (Chen et al., 2017; Clarke et al., 2021; Smits et al., 2020). One such study by Clarke, Van Bockstaele, et al. (2020) examined the effects of tDCS on emotional regulation, attentional bias, and emotional reactivity in response to negative content. Participants were given either active or sham tDCS to the left DLPFC and their attentional patterns were then measured via a dot-probe task involving negative-neutral image pairs. The impact on emotional reactivity to negative content was then assessed through the delivery of a block of videos depicting negative content. While no effects of tDCS on biased attention were observed, those who received active tDCS reported smaller increases in negative mood after viewing the negative videos, compared to those in the sham condition. This finding was corroborated in a similar study by Clarke et al. (2021), where participants who received active tDCS again showed smaller increases in negative mood in response to videos depicting negative emotional content compared to those in the sham condition. These studies provide evidence that tDCS targeting prefrontal areas may enhance emotional resilience by attenuating negative emotional reactivity in response to negative content.

The effects of tDCS have also been examined in the context of both emotional reactivity and attentional bias concurrently. Chen et al. (2017) studied the effects of tDCS on emotional reactivity in response to an emotional stressor presented as negative-neutral video pairs, and measured anxiety reactivity with a mood scale before and after delivering the emotional stressor. Results of this study showed that participants who received active tDCS to the left DLPFC had lower attentional bias towards threat, and attentional bias accounted for the association between tDCS and anxiety reactivity. These results not only provide further evidence for tDCS attenuation of attentional bias towards threat, but also suggest that tDCS may partially exert its impact on emotional resilience via changes in biased attention.

It is important to note, however, that none of these studies, nor any in the literature to our knowledge, have examined how modulation of frontal activity via tDCS impacts both emotional reactivity and attentional bias for positive emotional information. In considering the potential cognitive and emotional effects of frontal tDCS in relation to positive information, two recognised functions of the lateral prefrontal cortex are relevant. The first function concerns this region's role in inhibitory control. Evidence has shown that prefrontal areas such as the DLPFC are involved in the inhibition of attention towards distracting information, with DLPFC stimulation in particular increasing inhibitory attentional control (Friehs & Frings, 2018). The observation that lateral prefrontal stimulation can decrease attention towards negative information may therefore represent an extension of this inhibitory control function to reduce attentional deployment to salient negative information (Chen et al., 2017; Ironside et al., 2016). However, it is unclear whether the inhibitory role of the prefrontal cortex may also extend to the inhibition of attention towards positive information. If it is the case that prefrontal areas inhibit attentional deployment to salient distracting information in the context of both negative and positive information, we may observe a reduction in attentional bias towards both types of information as a result of tDCS targeting this area and, subsequently, lower emotional reactivity to negative as well as positive content. We refer to this as the *general affective inhibition hypothesis.*

The other relevant function of lateral prefrontal areas relates to the regulation of emotion in line with an individual's current goal. Research has established the role of prefrontal areas in the regulation of affectivity whereby anodal tDCS leads to an increase or decrease in emotional reactivity in line with an individual's intended pattern of emotional regulation (Clarke et al., 2021; Feeser et al., 2014). In line with the goal of maintaining adaptive emotional functioning, if individuals generally seek to reduce negative emotional states and increase positive emotional states, and lateral prefrontal areas potentially facilitate this, it is entirely possible that tDCS targeting the DLPFC may attenuate negative emotional reactions and increase positive emotional reactions. Given established associations between selective attention and emotion, we would expect that such emotional effects will be associated with concurrent reduction in attentional bias towards negative content and an increase in attentional bias towards positive information. We refer to this as the *affective regulation hypothesis*.

Therefore, the key aim of the current study was to examine the effects of tDCS on eye-tracked attentional bias towards both negative and positive information, and its effects on emotional reactivity in response to both negative and positive content. In order to achieve this aim, we conducted a single-blind experimental study with a between-subjects factor of tDCS condition (active vs sham) and within-subjects factors of time (baseline vs post-tDCS), stimulus type (negative vs positive), and mood elicitation type (negative vs positive). We assessed participants' attentional bias towards both negative and positive information via eye-tracking both before and after receiving active or sham tDCS to the left DLPFC. We specifically targeted the left DLPFC as past research has demonstrated that stimulation to this area can influence emotional and attentional processes (Chen et al., 2017; Clarke et al., 2021; Clarke, Van Bockstaele, et al., 2020; Heeren et al., 2015). We subsequently assessed the effects of tDCS on both negative and positive reactivity in response to negative and positive content. To further corroborate self-report measures of mood and arousal, we also included an objective measure of emotional arousal via heart rate variability (HRV). HRV measures capture the variance of time in between individual heartbeats (Laborde et al., 2017; Shaffer & Ginsberg, 2017) with higher levels of heart rate variability reflecting less parasympathetic arousal (low arousal) and low levels reflecting higher parasympathetic arousal. Such measures have been utilised in previous studies examining tDCS and anxious symptomology (Chalmers et al., 2014; Marques et al., 2018; Myruski et al., 2021).

In regard to attentional bias towards negative information, we hypothesised that, as per past findings, those receiving active tDCS would show decreased attentional bias towards negative information. Secondly, we hypothesised that tDCS would result in reduced negative reactivity in response to negative content, again consistent with past findings. In regard to the effects of tDCS on attentional bias towards positive information and positive emotional reactivity, we considered two alternative hypotheses. Our general affective inhibition hypothesis firstly predicts that tDCS would reduce attentional bias towards emotional content in general, thus corresponding to decreased attentional bias towards positive information. Secondly, this hypothesis predicts that tDCS would reduce high arousal emotion in general, thus corresponding to reduced positive reactivity in response to positive content for those receiving active tDCS. Alternatively, the affective regulation hypothesis suggests that DLPFC tDCS may shift cognitive and emotional processes towards more positive information generally and therefore predicts that active tDCS would specifically reduce attentional bias towards negative information, and also increase attentional bias towards positive information. Similarly, this hypothesis predicts that tDCS would reduce negative reactivity in response to negative content, and conversely increase positive reactivity in response to positive content.

Method

Participants

Using convenience sampling, we recruited 101 participants (M_{age} = 22.57, *SD* = 5.60; 66.33% female) through the Curtin University School of Psychology participant pool and social media advertising. Participants recruited within the university received course credit, and external participants were placed in a prize draw to win a $100 voucher. Eligibility requirements for inclusion in the study were that participants must not have any contraindications for tDCS, including neurological disorders, current use of psychoactive medication, active skin disease, metal implants or devices in the body, history of migraine or frequent headaches, history of faintness, any unstable medical condition, or current use of a hearing aid. They were also required to have normal or corrected-to-normal vision. These criteria were made known to the participants upon initial registration for the study and at the beginning of the experiment when obtaining informed consent. Ethics approval was obtained from the Curtin University Human Research Ethics Committee (ethics approval number HRE2021-0136).

Sensitivity analyses determined that our sample was sufficient to detect small-to-medium effects, based on an alpha level of 0.05 and power level of 0.8 (Faul et al., 2009). This is consistent with past studies investigating tDCS, attention, and emotional reactivity (Chen et al., 2017; Clarke, Sprlyan, et al., 2020; Smits et al., 2020).

Measures

Depression Anxiety and Stress Scale 21

We administered the 21-item Depression Anxiety and Stress Scale (DASS-21; Lovibond & Lovibond, 1995) to assess group levels of depression, anxiety, and stress symptoms over the past week. It contains three subscales that measure the respondent's frequency of depression, anxiety, and stress symptoms (e.g., "I felt down-hearted and blue") on a seven-point Likert scale, with possible scores on each item ranging from 0 (*Did not apply to me at all*) to 3 (*Applied to me very much, or most of the time*). Summed scores on each subscale indicate the respondent's overall levels of depression, anxiety, and stress. We also calculated a general measure of mental distress by summing the three total subscale scores. The reliability and validity of the DASS-21 have been established in a variety of samples (Oei et al., 2013), including undergraduate students (Osman et al., 2012). Each subscale of the DASS-21 was found to have good internal consistency in our sample, with Cronbach's alpha levels at .93, .78, and .86 for the depression, anxiety, and stress subscales, respectively.

Positive and Negative Affect Schedule

We administered the Positive and Negative Affect Schedule (PANAS; Watson et al., 1988) to examine group levels of positive and negative affect over the past week. It comprises two 10-item scales that measure the respondent's levels of positive affect (PA) and negative affect (NA). Respondents in our study indicated the extent to which they had experienced a given emotion over the past week (e.g., "excited", "hostile", "proud") using a five-point Likert scale, with possible scores on each item ranging from 1 (*Very slightly or not at all*) to 5 (*Extremely*). Summed scores on each subscale indicate the respondent's overall levels of PA and NA. Both subscales of the PANAS have displayed good psychometric properties in various populations (Crawford & Henry, 2004; Merz et al., 2013; Serafini et al., 2016). Both the PA and NA subscales were found to have good internal consistency in our sample, with Cronbach's alpha levels at .89 and .85, respectively. Discriminant validity between the two subscales was also good in our sample, $r(101) = .10$, $p = .338$.

State Anxiety Assessment - Spielberger State-Trait Anxiety Inventory (Short Form)

To assess state anxiety at baseline, we administered the short form of the Spielberger State-Trait Anxiety Inventory (STAI-S; Marteau & Bekker, 1992). It comprises six items that ask the respondent about their current levels of anxiety, with items such as "I feel upset" and "I am tense". Respondents answer on a four-item Likert scale with scores ranging from 1 (*Not at all*) to 4 (*Very much*). Scores on items 1, 4, and 5 are reversed and resulting scores are summed, resulting in a total measure of current anxiety. Good psychometric properties have been reported for the short form of the STAI-S (Marteau & Bekker, 1992;

Tluczek et al., 2009). This measure was found to have good internal consistency in our sample, with a Cronbach's alpha level of .74.

Attentional Bias Measure

Image stimuli. Images used in the attention bias assessment task were sourced from the International Affective Picture System (IAPS; Lang et al., 2008) and the Open Affective Standardized Image Set (OASIS; Kurdi et al., 2017) databases, and were paired to create negative-neutral and positive-neutral stimulus pairs. Standardised mean emotional ratings exist for images in both databases on dimensions including valence (negative vs positive) and arousal (the strength of emotional response elicited by the image). The scales used to rate these images ranged from 1–9 (IAPS) and 1–7 (OASIS), with higher valence scores indicating more positive emotional ratings, and higher arousal scores indicating greater arousal. Negative, positive, and neutral images were selected based on their mean affective ratings for valence (IAPS: negative ≤ 4, positive ≥ 6, neutral 5–6; OASIS: negative ≤ 3, positive ≥ 5, neutral 4–4.5) and arousal (IAPS: negative ≥ 4, positive ≥ 4, neutral < 4; OASIS: negative ≥ 3, positive ≥ 3, neutral < 3). To ensure the salience of the emotion, negative and positive images that were rated higher on mean arousal were selected. Images were not selected if the standard deviation exceeded 2 on either or both the valence and arousal ratings, for both databases. We selected a total of 36 negative images, 36 positive images, and 72 neutral images (46 IAPS and 98 OASIS images). An additional eight neutral OASIS images were paired for use as practice trials. These pairs were each presented twice, for eight practice trials.

Images depicted content such as social scenes, faces, animals, and common objects. Image pairs were matched on overall visual complexity and colour schemes as closely as possible via visual inspection. Where possible, image pairs were also matched on the category of depicted content. This resulted in a total of 72 image pairs, which were then grouped into two different sets. Each set contained 18 negative-neutral pairs and 18 positive-neutral pairs (36 pairs total for each). Image pairs were allocated such that each set contained an approximately equal proportion of depicted content (e.g., images depicting happy faces were equally split across the sets). Mean luminance and standard deviation of each image were assessed based on both the HSV and CIELAB colour spaces using the Spectrum, Histogram, and Intensity Normalization and Equalization (SHINE) toolbox (Willenbockel et al., 2010) in MATLAB R2020b (The MathWorks, 2020). Within each image set, means and standard deviations for positive/negative images and their corresponding neutral images were compared. Independent samples *t* tests indicated that on average, there were no significant differences between the emotional images and their respective neutral images in either image set (all *p*s >.195). IAPS images were cropped and resized to a width and height of 500 x 400 pixels to match the OASIS images, with care taken to ensure no emotional content was removed from the image.

Trial structure. Attentional bias was measured via eye-tracking with salient-neutral image pairs (negative-neutral and positive-neutral pairs) presented on each trial. A probe was included at the conclusion of each trial to ensure participant engagement with the task. We produced the task using the Psychophysics Toolbox Version 3 (Brainard, 1997; Kleiner et al., 2007; Pelli, 1997) in MATLAB (The MathWorks, 2020). Images were presented on a medium grey background, with white probes (letters N and J) and instructional text. On each trial, participants were initially presented with a black fixation dot in the centre of the screen for 500ms. Then, the image pair was presented for 2000ms. Image width and height were 13.23 x 10.58cm, and images were aligned horizontally with 450mm of horizontal separation. A probe (letter N or J) then replaced one of the images, and participants were instructed to identify the letter as quickly and accurately as possible by responding on the keyboard accordingly. Intertrial intervals were variable at 500ms, 750ms, and 1000ms. Drift correction occurred in the middle of each set. The image pair, probe type (N/J), probe position (left/right), and image position (left/right) were counterbalanced across trials and delivered in randomised blocks.

Image pairs were each presented in four randomised blocks, resulting in 72 negative-neutral and 72 positive-neutral (144 total) trials in total for each assessment. Each participant completed one assessment at baseline before receiving tDCS, and the second after receiving either active or sham tDCS. Both stimulus sets were presented once to every participant, and the order of the sets (baseline/post-tDCS) was counterbalanced across participants.

Eye-tracker. Eye gaze was assessed via eye movement captured from the right eye during the task using a tower-mounted EyeLink 1000 Plus eye-tracker (SR Research, n.d.). Gaze was captured at 1000hz using infrared pupil centre corneal reflection. Participants were seated with their heads placed on a chin rest, with their eyes approximately 57cm away from the monitor and aligned with the centre of the monitor. The width and height of the images were 13.23 x 10.58cm, resulting in a visual angle of approximately 13.24 x 10.60°.

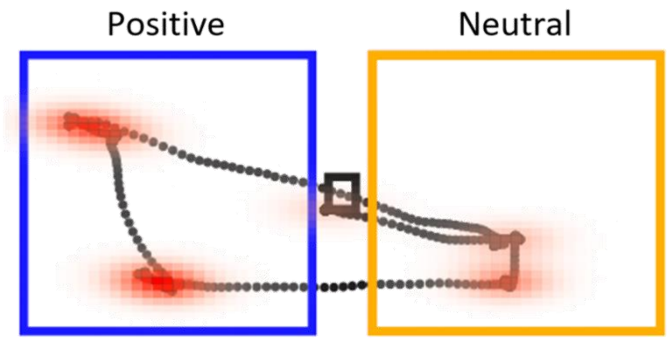
Participants completed the experiment on a 24-inch 1920 x 1080px colour monitor. The running of the tasks was controlled from a separate computer and monitor concealed from the participant with a partition. Practice trials were completed once at the beginning of the first block of trials, and 5-point calibration and validation were completed before each block of attentional trials (3 times in total).

Attentional bias index. Dwell time was used as the critical dependent measure of attention bias and was defined as the total number of milliseconds the participant fixated over each stimulus image. Our choice to exclusively examine dwell time was guided by Chen et al. (2017), which focused on dwell time as opposed to other measures of attentional bias (such as direction of first fixation). Fixations under 200ms and those outside the target areas (salient and neutral image stimulus) were excluded from the total dwell time calculation.

An attentional bias index score for each stimulus was computed by subtracting the total eye-gaze dwell time aligned with the neutral image from the total dwell time aligned with the corresponding salient image, resulting in an attentional bias index score for each individual trial. For each participant, we then separately calculated the mean attentional bias index score for trials containing negative stimuli and trials containing positive stimuli, for both the baseline and post-tDCS assessment blocks, with higher scores indicating greater attentional bias towards the salient stimuli. To illustrate, Figure 2.1 represents a recorded trial in which the participant displayed greater dwell time over the positive stimulus compared to the neutral stimulus.

Figure 2.1

A Sample of Recorded Eye Gaze over the Positive and Neutral Image in a Positive-Neutral Trial



Note. The red pixels depict dwell time over the images, with higher colour saturation indicating longer dwell time. Each distinct hot spot represents a fixation. Eye gaze path is represented by the grey points, with gaze path beginning at the centre fixation square. Figure is not to scale.

tDCS

Stimulation was given using a portable tDCS device powered by a 9-volt battery (Chattanooga Group, n.d.). Stimulation was delivered through two 4cm x 6cm silicone electrodes each encased in a saline-soaked sponge. The anode was placed over the left DLPFC (F3 as per the international 10-20 system), and the cathode was placed on the right superior trapezius muscle. Electrodes were held in place using fabric headbands (anode) and adhesive tape (cathode). All participants were led to believe that they would be receiving a full 20-minute dose of tDCS as outlined in the information sheets. Participants in the active condition received 20 minutes of stimulation with a ramp-up time of one minute, and the current was set at 1.5mA (current density of 0.0625 mA/cm^2). While some research has shown that stronger anodal tDCS intensities (e.g., 1.5–2.0mA) may produce greater cognitive effects (Dedoncker et al., 2016), other findings have suggested that higher intensities (e.g., 2.0mA) have the potential to cause inhibitory cortical effects (Goldsworthy & Hordacre, 2017). Therefore, we chose a current of 1.5mA to facilitate cortical excitability whilst reducing the potential inhibitory effects of higher doses. For those in the sham condition, the current was set at 1.0mA (current density of 0.0416 mA/cm^2) and was covertly ramped down completely after participants had received one minute of stimulation. During the 20 minutes of active or sham stimulation, all participants completed a set of distraction filler tasks. Filler tasks consisted of various number and word tasks and were designed to be as emotionally neutral as possible. Neutral words were sourced from the Affective Norms for English Words (ANEW; Bradley & Lang, 1999) and were selected based on their mean valence rating (≥ 5 and ≤ 6).

Mood Elicitation Task

A video viewing task was employed to induce negative and positive mood. Participants viewed one block of negative videos and one block of positive videos, each separated by a block of neutral videos (see Figure 2.2). Each block was six minutes long. The videos were of a high-arousal negative, neutral, and high-arousal positive valence, and each block comprised two separate clips. The negative and positive clips were selected based on subjective ratings by 15 judges, with an emotional intensity scale ranging from 0 to 100 and a film pleasantness scale ranging from -50 to +50. Of the 32 film scenes rated in the set, those that were rated lower on emotional intensity (< 40) were initially excluded. Two negative and two positive films were selected based on low (< -20) and high (> 20) pleasantness ratings. Final negative film selections were scenes from *The Blair Witch Project* (Myrick & Sánchez, 1999) and *The Shining* (Kubrick, 1980), and final positive film selections were scenes from *10 Things I Hate About You* (Junger, 1999) and *500 Days Of Summer* (Webb, 2009). To reduce potential carryover effects from either emotional video blocks, two YouTube clips depicting non-emotional content were selected to play in between the emotional videos (Bunnings Warehouse, 2015; TUK Crafts, 2014). The videos were presented in one of two orders: negative-neutral-positive or positive-neutral-negative (see Figure 2.2), with the order of delivery counterbalanced across participants. Participants wore headphones during the playing of the video and maximised the video on screen before viewing.

Figure 2.2

Order of Main Experimental Tasks

Note. BQ = baseline questionnaires; Base = baseline; AB = attentional bias task; FT = filler tasks; ER = emotional reactivity; Neg = negative; Neut = neutral; Pos = positive. Participants first completed the baseline emotional scales and demographic questionnaires, including the Depression Anxiety and Stress Scale 21, Positive and Negative Affect Schedule, and Spielberger State-Trait Anxiety Inventory (Short Form). They then completed the eye-tracked attentional bias task at baseline, followed by 20 minutes of either active or sham tDCS whilst performing the filler tasks. Participants then completed the post-tDCS eye-tracked attentional bias task. They then completed the mood elicitation task in which they viewed three videos and completed the self-report emotional reactivity scales at baseline and after each video (four time points). This figure is illustrative of participants who viewed the videos in negative-neutral-positive order, while an equal proportion viewed them in positive-neutral-negative order.

Self-reported emotional reactivity in response to the videos was assessed using three 11-point Likert scales. The scales ranged from 1 to 11 and measured participants' current levels of high-arousal negative affect ("Not at all anxious" – "Very anxious"), high-arousal positive affect ("Not at all happy" – "Very happy"), and overall emotional arousal ("Not at all aroused" – "Very aroused"). A short definition was included for the term "arousal" to avoid ambiguity. The scales were administered at four time points: immediately before the first emotional video, after the first emotional video, after the neutral video, and after the second emotional video (see Figure 2.2).

Heart Rate Variability

To provide an objective indicator of physiological response to emotional content, participants' HRV was tracked using a Firstbeat Bodyguard 2 HRV device (Firstbeat Technologies Oy, n.d.). HRV data were processed using Kubios HRV Premium (Kubios Oy, 2019). HRV was assessed during three five-minute blocks. This was assessed during a baseline period (before tDCS whilst completing questionnaires), during the first emotional video, and during the second emotional video (see Figure 2.2). We used the commonly employed root mean square of successive differences (RMSSD) as our measure of HRV, with lower measures taken as an indication of greater emotional arousal (Laborde et al., 2017).

Procedure

Participants were pre-allocated to the active or sham tDCS condition via participant number in an alternating manner according to their order of participation in the experiment. Upon arrival, participants first read the study information and provided informed consent after having the opportunity to ask any questions. Participants were then instructed on the fitting of the HRV monitor and they attached it in private. The participant was then seated and asked to complete the demographic, DASS-21, PANAS, and STAI-S questionnaires. Then, they completed the practice image trials which were presented for 500ms, followed by the baseline attentional bias assessment task, which took approximately 25 minutes in total. Then, they were fitted with the tDCS equipment and received either active or sham tDCS whilst performing the filler tasks. Following 20 minutes of active or sham stimulation, tDCS equipment was removed and the participant completed the post-tDCS attention task, which took approximately 25 minutes in total.

Once all attentional tasks were completed, the participant completed the first set of emotional reactivity scales. Then, they watched the first emotional video and completed another set of emotional reactivity scales. They were then shown the neutral video and completed the emotional reactivity scales again, followed by the remaining emotional video and a final set of emotional reactivity scales.

After completing the final emotion reactivity scales, the participant was then informed in the questionnaire of the existence of both an active and sham tDCS condition. They were then asked whether they believed they were in the active or sham tDCS condition or were unsure. Upon completion of the survey, the participant was redirected to a separate Qualtrics survey where they could input their contact details for either the prize draw (community participants) or to receive credit points (undergraduate participants).

At the conclusion of the experiment, the participant removed the HRV monitor in private. Participants were fully debriefed and given the opportunity to ask questions or raise any concerns. Participants who watched the negative video last were given the option to watch a subjectively pleasant video at the conclusion of the experiment. Overall, the experiment took approximately one hour and 40 minutes to complete. The participant information, consent form, questionnaires, filler tasks, and emotional reactivity tasks were delivered via a survey created in Qualtrics (Version May 2021). Participants were provided with a copy of the participant information via email prior to their participation. Videos were hosted on Vimeo (https://www.vimeo.com) and embedded within the Qualtrics survey. Figure 2.2 depicts the order in which the main experimental tasks were completed.

Results

Data Preparation

Seven participants returned no response on one item of the baseline questionnaires (two DASS-21 items and five PANAS items). These data were replaced by creating an average of each of these participants' total observed responses for the relevant subscale and multiplying it by the expected number of responses, to create an equivalent score for each scale.

Group Characteristics

Independent samples *t* tests indicated no between-group differences on any continuous variable at baseline, largest $t = 1.30$, all *p*s > .196. Chi-square tests of contingencies indicated that the groups did not differ on gender ratio, $\chi^2(2, N = 101) = 2.12$, $p = .346$ or handedness, $\chi^2(2, N = 101) = 1.43$, $p = .488$. Some violations of the assumption of normality were observed upon inspection of histograms, but we did not consider this to be problematic for our planned analyses due to our large sample size (> 40; Ghasemi & Zahediasl, 2012). Table 2.1 presents a summary of the descriptive data for each experimental group and the total sample.

Table 2.1

Participant Number, Gender, Age, Handedness, DASS-21 Subscale and Total Scores, PANAS Subscale Scores, and STAI-S Scores by tDCS Condition and Total Sample

	tDCS condition		
	Active	Sham	Total sample
Total participants (*N*)	51	50	101
Gender (%)			
Female	60.78	72.00	66.34
Male	37.25	28.00	32.67
Non-binary	1.96	0.00	0.99
Age (Years)			
M (SD)	23.14 (6.12)	22.00 (5.00)	22.57 (5.60)
Handedness (%)			
Right-handed	90.20	88.00	89.11
Left-handed	7.84	12.00	9.90
Mixed handed / Ambidextrous	1.96	0.00	0.99
DASS-21 score			
Depression			
M (SD)	4.8 (4.6)	5.1 (4.9)	5.0 (4.7)
Anxiety			
M (SD)	3.5 (3.6)	3.4 (3.0)	3.5 (3.3)
Stress			
M (SD)	7.2 (4.9)	6.3 (3.8)	6.8 (4.4)
Total score			
M (SD)	15.6 (11.8)	14.8 (9.8)	15.2 (10.9)
PANAS scores			
PA			
M (SD)	29.1 (7.0)	27.1 (8.2)	28.1 (7.7)
NA			
M (SD)	15.0 (5.4)	14.6 (4.7)	14.8 (5.0)
STAI-S score			
M (SD)	11.2 (3.1)	11.5 (2.8)	11.3 (3.0)

Note. DASS-21 = Depression Anxiety and Stress Scale 21; PANAS = Positive and Negative Affect Schedule; PA = Positive affect; NA = Negative affect; STAI-S = Spielberger State-Trait Anxiety Inventory (Short Form). Standard deviations are given in parentheses.

Effects of tDCS on Attentional Bias

To examine the effects of tDCS on attentional bias, we ran a 2 x 2 x 2 mixed model analysis of variance (ANOVA). Our dependent measure was attentional bias index score, our within-subjects factors were time (baseline vs post-tDCS) and stimulus type (negative vs positive), and our between-subjects factor was tDCS condition (active vs sham). Technical difficulties occurred with eight participants' eye-tracking which resulted in lost data, and they were therefore excluded from the following analysis. Descriptives for this ANOVA are presented in Table 2.2.

Table 2.2

Estimated Marginal Means, Standard Errors, and 95% Confidence Intervals of Attentional Bias

Type	Time	tDCS condition							
		Active				Sham			
		M	95% CI		SE	M	95% CI		SE
			LL	UL			LL	UL	
Neg	Baseline	-566.45	-624.32	-508.58	29.13	-605.16	-662.41	-547.91	28.82
	Post-tDCS	-629.75	-680.15	-579.34	25.38	-635.67	-685.54	-585.80	25.11
Pos	Baseline	173.47	124.04	222.90	24.88	173.83	124.93	222.73	24.62
	Post-tDCS	237.15	178.78	295.51	29.38	257.44	199.70	315.18	29.07

Note. CI = confidence intervals; LL = lower limit; UL = upper limit; SE = standard error of the mean; Neg = negative; Pos = positive. "Type" refers to trial type (positive-neutral vs negative-neutral).

A significant main effect of stimulus type was found, $F(1, 91) = 943.56$, $p < .001$, partial $\eta^2 = .91$, which showed that participants displayed a greater attentional bias towards positive images within positive-neutral trials ($M = 210.47$, $SE = 17.20$, 95% CI [176.30, 244.65]), compared to their attentional bias towards negative images within negative-neutral trials ($M = -609.26$, $SE = 17.48$, 95% CI [-643.98, -574.53]). An interaction effect was also found involving time and stimulus type, $F(1, 91) = 23.28$, $p < .001$, partial $\eta^2 = .20$, which showed that across both tDCS conditions, participants' attentional bias towards positive images increased from baseline ($M = 173.65$, $SE = 17.50$, 95% CI [138.88, 208.41]) to post-tDCS ($M = 247.29$, $SE = 20.67$, 95% CI [206.24, 288.34]), and participants' attentional bias towards negative images decreased from baseline ($M = -585.80$, $SE = 20.49$, 95% CI [-626.51, -545.10]) to post-tDCS ($M = -632.71$, $SE = 17.85$, 95% CI [-668.16, 597.25]). No other significant main effects or interactions were found (all $F < 1.59$, all *p*s > .211).

Effects of tDCS on Self-Reported Emotional Reactivity

To examine the effects of tDCS on emotional reactivity in response to both negative and positive information, we ran a 2 x 2 mixed model ANCOVA for each type of dependent measure (self-reported anxiety, happiness, and arousal). For each analysis, our within-subjects factor was video type (negative vs positive), and our between-subjects factor was tDCS condition (active vs sham). The analyses were conducted on the total sample of 101 participants. Each baseline measure of self-reported reactivity was included as a covariate in its corresponding analysis. To account for multiple comparisons for each of the measures examined (negative reactivity, positive reactivity, and arousal), we also employed the Bonferroni corrected alpha level of $\alpha = 0.017$ (conventional significance effects are also reported). Descriptives for these ANCOVAs are presented in Table 2.3.

Table 2.3

Estimated Marginal Means, Standard Errors, and 95% Confidence Intervals of Self-Reported Emotional Reactivity

Variable	Video type	tDCS condition							
		Active				Sham			
		M	95% CI		SE	M	95% CI		SE
			LL	UL			LL	UL	
Anxiety	Neg	5.58	4.88	6.27	0.35	5.61	4.91	6.32	0.35
	Pos	2.04	1.67	2.41	0.19	2.28	1.90	2.65	0.19
Happiness	Neg	5.36	4.84	5.87	0.26	4.58	4.05	5.10	0.26
	Pos	8.52	8.08	8.97	0.22	8.11	7.66	8.56	0.23
Arousal	Neg	5.89	5.25	6.53	0.32	6.11	5.46	6.76	0.33
	Pos	6.44	5.84	7.04	0.30	5.75	5.15	6.35	0.30

Note. CI = confidence intervals; LL = lower limit; UL = upper limit; SE = standard error of the mean; Neg = negative; Pos = positive.

Negative Reactivity

For the self-report negative emotion scale, a significant main effect of video type was found, $F(1, 98) = 19.61$, $p < .001$, partial $\eta^2 = .17$, indicating that overall, participants reported significantly greater levels of anxiety in response to the negative video ($M = 5.59$, $SE = 0.25$, 95% CI [5.10, 6.09]) compared to the positive video ($M = 2.16$, $SE = 0.13$, 95% CI [1.90, 2.42]). No other significant effects were found, largest $F = 0.22$, all *p*s > .641.

Positive Reactivity

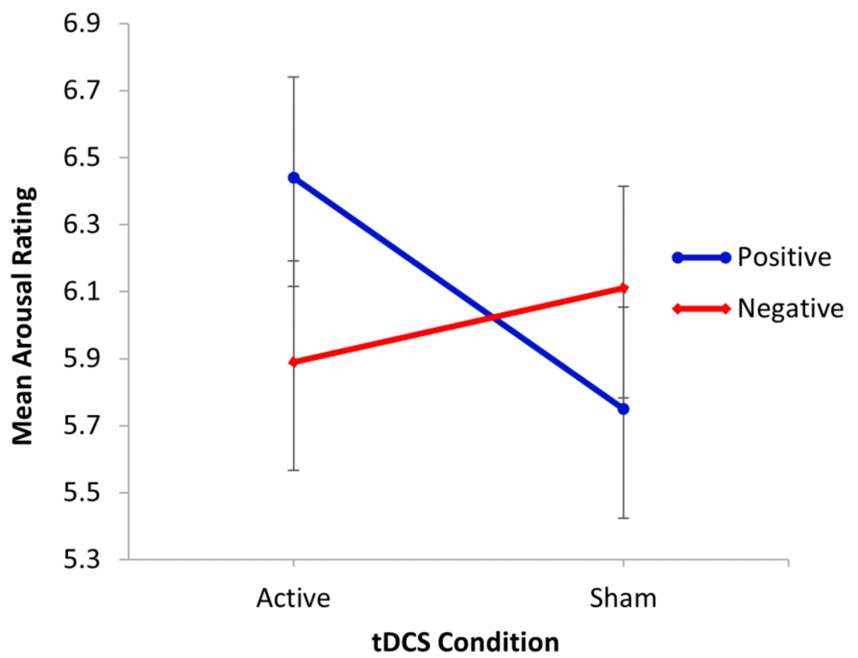
A significant main effect of video type was found, $F(1, 98) = 7.56$, $p = .007$, partial $\eta^2 = .07$, indicating that overall, participants reported greater levels of happy mood in response to the positive video ($M = 8.31$, $SE = 0.16$, 95% CI [8.00, 8.63]) compared to the negative video ($M = 4.97$, $SE = 0.18$, 95% CI [4.60, 5.33]). A main effect of tDCS condition was also found, $F(1, 98) = 5.99$, $p = .016$, partial $\eta^2 = .06$. The pattern of this effect was such that that those in the active tDCS condition reported greater feelings of happiness across both video types ($M = 6.94$, $SE = 0.17$, 95% CI [6.60, 7.28]), compared to those in the sham condition ($M = 6.34$, $SE = 0.17$, 95% CI [6.00, 6.69]). No interaction effect was found involving tDCS and video type, $F(1, 98) = 0.56$, $p = .456$, partial $\eta^2 = .01$.

Arousal

No significant main effects of tDCS condition or video type were observed, largest F = 0.36, all *ps* > .550. An interaction effect involving video type and tDCS condition was found, $F(1, 98) = 4.97$, $p = .028$, partial $\eta^2 = .05$, indicating that participants in the active tDCS condition reported greater arousal in response to the positive video (M = 6.44 , SE = 0.30, 95% CI [5.84, 7.04]) compared to the negative video (M = 5.89, SE = 0.32, 95% CI [5.25, 6.53]), whereas those in the sham condition reported greater arousal in response to the negative video (M = 6.11, SE = 0.33, 95% CI [5.46, 6.76]) compared to the positive video (M = 5.75, SE = 0.30, 95% CI [5.15, 6.35]. Figure 2.3 illustrates this pattern of effects. It should be noted, however, that although this result met conventional significance of $\alpha = 0.05$, it did not reach Bonferroni-corrected significance of $\alpha = 0.017$.

Figure 2.3

Estimated Marginal Means of Arousal Ratings



Note. “Positive” and “Negative” refer to video type. Error bars represent standard errors of the mean.

Effects of tDCS on Physiological Arousal

To examine the effects of tDCS and emotional experience on physiological arousal in response to both negative and positive stimuli, we ran a 2 x 2 mixed model ANCOVA with the RMSSD measure of HRV as the dependent variable. Our within-subjects factor was video type (negative vs positive), our between-subjects factor was tDCS condition (active vs sham), and baseline RMSSD was included as a covariate. Two participants were excluded from this analysis due to failed HRV measurement, which resulted in a sample size of 99. No effects were found with this analysis, largest $F = 1.38$, all ps > .243. Descriptives for this ANCOVA are presented in Table 2.4.

Table 2.4

Estimated Marginal Means, Standard Errors, and 95% Confidence Intervals of Physiological Arousal

Video type	tDCS condition							
	Active				Sham			
	M	95% CI		SE	M	95% CI		SE
		LL	UL			LL	UL	
Negative	47.56	42.61	52.52	2.49	48.63	43.73	53.53	2.47
Positive	49.98	44.46	55.50	2.78	51.57	46.11	57.04	2.75

Note. CI = confidence intervals; LL = lower limit; UL = upper limit; SE = standard error of the mean.

Discussion

The current study aimed to examine the effects of tDCS to the left DLPFC on attentional bias towards both negative and positive information, as well as its effects on both negative and positive emotional reactivity in response to emotional content. In regard to attentional bias towards negative information, we hypothesised that, as per past findings, those receiving active tDCS would show decreased attentional bias towards negative information. This hypothesis was not supported, with results producing no evidence that tDCS affected attentional patterns towards negative information. Secondly, we hypothesised that tDCS would result in reduced negative reactivity in response to negative content. This was partially supported by self-reported emotional reactivity. While there was no effect in relation to self-reported anxious mood, the analysis of self-reported arousal indicated that those who received active tDCS reported greater arousal in response to positive content compared to negative content, whereas those who received sham tDCS reported greater arousal in response to negative content compared to positive content. It should be noted that this result only met conventional significance and not Bonferroni-corrected significance, and we must therefore be tentative in interpreting this pattern of results. There was no effect of tDCS on physiological arousal, however.

In regard to attentional bias towards positive information and positive reactivity, we considered two alternative hypotheses for the effects of tDCS on both attentional bias and emotional reactivity. The general affective inhibition hypothesis firstly predicted that tDCS would reduce attentional bias towards emotional content in general, thus corresponding to decreased attentional bias towards positive information. Secondly, this hypothesis predicted that tDCS would reduce high arousal emotion in general, thus corresponding to reduced positive reactivity in response to positive content. Our alternative affective regulation hypothesis firstly predicted that tDCS would shift cognitive and emotional processes towards more positive information generally, thus corresponding to reduced attentional bias towards negative information and increased attentional bias towards positive information. Secondly, this hypothesis predicted that tDCS would reduce negative reactivity in response to negative content, and conversely increase positive reactivity in response to positive content. The results examining patterns of biased attention provided no support for either hypothesis, finding no evidence of any effects of tDCS on attentional bias towards positive information. However, while there was no evidence of tDCS reducing anxious mood specifically, the affective regulation hypothesis was partially supported such that those who received active tDCS reported greater happy mood overall, compared to those in the sham tDCS group. Additionally, this hypothesis was supported by the effects on self-reported arousal. As mentioned previously, these results indicated reduced self-reported arousal in response to negative content and increased arousal in response to positive content as a result of active tDCS, while those in the sham condition showed the reverse effect. This effect was not also reflected in measures of physiological arousal with no effects observed on measures of HRV.

Our lack of findings regarding the effects of tDCS on attentional patterns was somewhat unexpected, particularly in the context of bias towards negative information. Past research has demonstrated that tDCS to the left DLPFC can reduce attentional bias to threatening information either alone (Chen et al., 2017; Ironside et al., 2019) or in combination with cognitive training that targets attentional bias (Clarke, Browning, et al., 2014; Heeren et al., 2015; Myruski et al., 2021). As such, the absence of such an effect in our study appears to be inconsistent with these past findings. In regard to attentional bias towards positive information, the present sample showed a general attentional preference for positive information. This is in line with previous research which has established that across general populations, attention tends to be biased towards positive stimuli compared to neutral stimuli (Pool et al., 2016). No significant effects of tDCS condition on patterns of attention to positive information were observed.

In considering the absence of tDCS-induced effects on selective attention to positive and negative information in the current study, it is possible that this may represent a genuine absence of tDCS effects on attention towards positive information. However, the failure to replicate the effect of tDCS on negative attention bias would suggest that the present lack of findings in relation to positive information should not necessarily be regarded as evidence for the absence of such an effect. As the present study did not replicate such previously observed effects of tDCS on negative attention bias, it is worth considering aspects of the current design that could have limited the ability of the present study to observe such effects. One possibility concerns the absence of participant pre-screening based on elevated levels of anxious or depressive symptomatology. As was evidenced by our results, participants had an overall preference for attending to positive information when compared to negative information, suggesting that our sample had an existing low level of attentional bias towards negative information. Therefore, this may have left little opportunity for tDCS to facilitate a reduction in attentional bias towards negative information or an increase in attentional bias towards positive information in our sample. Though this may be the case, some studies have provided evidence of tDCS-induced effects on patterns of attention in unselected samples (Chen et al., 2017; Ironside et al., 2016; Sanchez-Lopez et al., 2018). Nevertheless, future research may benefit from examining such effects in samples with elevated anxiety and/or depressive symptomatology.

An additional possibility is that requiring participants to identify and respond to probes on each trial could have interfered with naturalistic patterns of attention if, for instance, participants were particularly focussed on identifying the probe correctly, thus potentially reducing the tendency to remain engaged with a given stimulus for an extended period. Probes were included in the current study in order to encourage participant engagement, however, it may be preferable for future research to employ a free-viewing task format in which participants can view a set of stimuli without the interference of a response requirement. This may provide a more valid indication of attentional patterns that are not interrupted by arbitrary task requirements.

It is also possible that it would be beneficial to use more dynamic stimuli that are presented for a longer duration to facilitate the detection of tDCS-induced effects on attentional patterns. For example, in a study that did find a reduction in attentional bias towards threat following active tDCS, Chen et al. (2017) conducted eye-tracking on threat-neutral video pairs that were displayed for sustained durations of between eight and 15 seconds. While this stimulus was also designed as a simultaneous stressor, it may be worth expanding on this research by using a similar design in order to further examine the effects of tDCS on attentional patterns towards more complex stimuli not only in the context of negative information, but also positive information.

It is also worth considering whether the sequence of the stimulation delivery may have impacted the ability to detect tDCS-induced changes in attentional patterns. Studies utilising neurostimulation typically deliver the stimulation either online (concurrently with a cognitive measure) or offline, whereby cognitive changes are measured after the cessation of the stimulation (Woods et al., 2016). We chose to deliver tDCS offline before administering the second attentional bias measure, in order to ensure the participants in the active tDCS condition received a full 20-minute dose of stimulation before assessment. Some past studies have demonstrated attentional changes via offline anodal tDCS, which demonstrates that tDCS can produce short-term effects on attentional patterns even after the session has ceased (Chen et al., 2017; Ironside et al., 2016; Sanchez et al., 2016; Sanchez-Lopez et al., 2018). However, several other studies examining the cognitive effects of tDCS have yielded similar such effects using online tDCS delivery (Clarke, Sprlyan, et al., 2020; Feeser et al., 2014), including those examining attentional bias (Clarke, Browning, et al., 2014; Heeren et al., 2017; Myruski et al., 2021). Therefore, it is possible that online delivery of tDCS could increase the potential for detecting effects on attention and associated emotional patterns.

Furthermore, research has found that in addition to attentional bias towards threat-related stimuli, there is also evidence to suggest that individuals' attentional biases tend to fluctuate towards and away from threat-related information (Swick & Ashley, 2017). Specifically, attentional biases that indicate patterns of both hypervigilance and avoidance of threat-related stimuli appear to be implicated in anxiety (Clarke, Marinovic, et al., 2020; Zvielli et al., 2015). These variations in attentional vigilance, or attention bias variability, have mostly been examined in relation to anxiety disorders such as PTSD (Iacoviello et al., 2014; Naim et al., 2015; Swick & Ashley, 2017). The relatively brief 2000ms presentation used in the current study limited our ability to examine variations in attentional bias between paired stimuli. Therefore, using more complex stimuli and longer duration times in future research may also be helpful for examining patterns of attention bias variability not only in the context of negative information and anxiety, but also in the context of positive information and tDCS, as these have not been examined to our knowledge. Additionally, given that attention bias variability appears to be involved in psychological disorders, should tDCS potentially affect such patterns of attention this may have implications for the treatment of such disorders.

The present results examining the effects of tDCS on emotional reactivity demonstrated two main things. Firstly, active tDCS led to increased levels of self-reported happy mood overall. Though we saw no evidence of tDCS decreasing anxious mood specifically, this result is generally in line with past research that has demonstrated the potentially beneficial effects of tDCS on mood, such as decreased emotional reactivity in response to negative content (Clarke et al., 2021; Clarke, Van Bockstaele, et al., 2020). This finding could also be considered consistent with the affective regulation hypothesis. Systematic reviews assessing the potential therapeutic effects of tDCS have also demonstrated that tDCS may help decrease symptoms of anxiety and depression, though results are mixed and somewhat preliminary (Palm et al., 2016; Vicario et al., 2019).

However, none of these studies to our knowledge have assessed the emotional effects of tDCS in response to both negative and positive content, so our results may be considered novel. This result suggests that increasing cortical activity in the left DLPFC via tDCS may help increase positive mood in general, and it may therefore be important for future research to extend upon such findings in clinical populations or those with elevated trait levels of negative mood. These findings could also potentially inform the clinical value of tDCS delivered in conjunction with positive emotional content which may produce beneficial mood effects beyond that of tDCS delivered in isolation.

Secondly, we found that participants in the active tDCS condition reported higher self-reported arousal in response to positive content and lower arousal in response to negative content, with those in the sham tDCS condition showing the reverse pattern of effects. This finding is again consistent with the affective regulation hypothesis. This result is also somewhat novel as we measured emotional reactivity in response to both negative and positive content. This finding suggests that participants who received active tDCS may have been better able to modulate their emotional arousal in line with the emotional content being processed, that is, downregulating anxious mood in response to negative content and upregulating happy mood in response to positive content. This may provide further evidence for the left DLPFC's role in emotional regulation and, in particular, is consistent with the position that potentiating cortical activity in this region may enhance emotional regulation that is aligned with an individual's specific goals. As mentioned earlier, however, these results did not quite reach Bonferroni-corrected significance and as such it will be important to replicate such effects in subsequent research before drawing firm conclusions in relation to this. For example, it may be worth replicating this study using a sample with elevated negative emotion and lower positive emotion, as it is possible that having an unselected sample may have limited the ability to detect tDCS-induced effects on emotion or selective attention. Indeed, the observed pattern of attentional preference for more positive stimuli overall highlights the possibility that this effect may have been close to 'ceiling', therefore leaving less opportunity for tDCS-induced effects.

The aforementioned finding in relation to the tDCS-induced effects on emotional arousal also suggests that the emotional effects of tDCS may be enhanced when combined with tasks that involve goal-directed cognition. Though they were not instructed to regulate their emotional responses in a specific direction, it is possible that participants in the current study sought to maintain a generally positive affective state manifesting in the respective down- and up-regulation of arousal in response to negative and positive content. This may be another key factor as to why no tDCS-induced effects were found on attentional patterns, as we did not provide our participants with the goal of adopting a specific pattern of attention. As has been demonstrated in past research, tDCS has been shown to increase the effects of cognitive training that specifically targets attentional bias (Clarke, Browning, et al., 2014; Heeren et al., 2015). Attention bias modification (ABM) is a task that is used to alter patterns of attention, often away from threatening information (Heeren et al., 2015; Mogg & Bradley, 2016). Though ABM alone has shown some promise as an intervention for anxiety disorders, findings across the literature have been somewhat inconsistent (Clarke, Notebaert, et al., 2014; Hakamata et al., 2010; Mogg & Bradley, 2016; Mogg et al., 2017). Therefore, some studies have sought to examine whether potentiating activity in the left DLPFC would enhance the effectiveness of ABM training on attentional bias towards threatening information. Clarke, Browning, et al. (2014) found that in a nonclinical sample, ABM combined with sham tDCS did not result in significant changes in attentional patterns. However, when combined with anodal tDCS to the left DLPFC, ABM resulted in significant modifications in attentional patterns aligned with the intended direction of the training (towards vs away from threat). Heeren et al. (2015) found a similar pattern of results in a sample with high trait anxiety, in that ABM led to significantly reduced attentional bias towards threatening information when combined with anodal tDCS to the left DLPFC, but not when combined with sham or cathodal tDCS. These studies show that tDCS may have greater effectiveness when combined with a task in which individuals are trained to adopt specific patterns of attention. It may therefore be important to examine tDCS in combination with training such as ABM, as this may help inform potential avenues through which tDCS could be used to reduce anxious symptomatology and promote psychological wellbeing.

Finally, no effects of tDCS on physiological arousal were observed. HRV has been examined in the context of anxious symptomatology (Chalmers et al., 2014) and attentional bias (Myruski et al., 2021), and some research has found that tDCS targeting prefrontal areas can affect HRV (Brunoni, Vanderhasselt, et al., 2013; Marques et al., 2018). However, no such effects were found in the current study. Inspection of our HRV samples revealed that the data contained a significant amount of noise, which may have contributed to the lack of results. Additionally, though HRV has been shown to indicate changes in state emotion

(Dimitriev et al., 2016), it may be the case that HRV is better suited to measuring trait factors, as has been demonstrated in studies examining anxious and depressive symptomatology (Brunoni, Kemp, et al., 2013; Chalmers et al., 2014, 2016), as well as positive affect (Duarte & Pinto-Gouveia, 2017). Therefore, it may be beneficial to use an alternative objective measure of emotional arousal that is more sensitive to acute changes in state emotion, such as electrodermal activity (Feeser et al., 2014).

In conclusion, the current study examined the effects of tDCS on patterns of attention and emotional reactivity towards both negative and positive information. We found no evidence of tDCS-induced effects on attentional bias towards either negative or positive information. However, though results are somewhat tentative, we found some evidence that tDCS may enhance emotional regulation that is aligned with intent, and may increase positive mood. These findings provide further support for the role of the left DLPFC on emotional regulation and suggest that potentiating activity in prefrontal areas may have positive effects on overall mood. This could have implications for potential treatments for mood disorders, for example, so further extensions in this area of research may benefit from the inclusion of clinical samples or samples high in anxious or depressive symptomatology. It may also be of benefit to examine tDCS in conjunction with cognitive training such as ABM in such samples, as this may be a promising intervention for mood disorders and may promote overall positive psychological health.

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