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The role of attentional flexibility during emotion processing in resilience and emotional disorders

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“All's well that ends well.”

Shakespeare

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CHAPTER 1

GENERAL INTRODUCTION

ANXIETY AND VULNERABILITY TO ANXIETY DISORDERS

Anxiety and Fear

The terms “anxiety” and “fear” are often used interchangeably. Both of these terms refer to an unpleasant emotional state characterized by tension and apprehension in response to threatening/dangerous situations (Rachman, 1998). However, a distinction can be made considering the cause and course of them (Rachman, 1998; Barlow, 2002). Fear is an intense feeling related to an immediate threat and it usually diminishes when the source of threat disappears, whereas anxiety often is less intense than fear and it can exist even when there is not an immediate threat. Hence, the source of anxiety is often less clear, less predictable and it can be harder to control.

From an evolutionary perspective, both fear (i.e. to deal with dangerous situations) and anxiety (i.e. to detect threat earlier, better preparation for a dangerous situation) are considered adaptive states that are of key benefit to increasing chances of survival (Eysenck, 1992; Clark & Beck, 2011). However, when these negative emotional states are prolonged in the absence of an immediate threat, they may actually become non-adaptive which is typically the case for anxiety disorders (Barlow, 2002; Gray & McNaughton, 2003; Clark & Beck, 2011).

Vulnerability to Anxiety Disorders

Anxiety disorders are amongst the most common problems of modern society with an estimated one-year prevalence rate of 18.1% in the US (Kessler, Chiu, Demler, & Walters, 2005); and a global prevalence rate (considering 6-month to 12-month estimates) ranging from 2.4% to 29.8% across forty-four countries (Baxter, Scott, Vos, & Whiteford, 2013). Therefore, understanding risk factors for the development and maintenance of these disorders has great importance.

Among many possible risk factors leading to anxiety disorders (i.e. genetics, early life experiences, trauma, personality factors; Barlow, 2000), cognitive risk factors are crucial since they are predominant features of anxiety, underlying various anxiety disorders (Eysenck, 1992). Moreover, cognitive factors are frequently considered the more proximal causes of anxiety, where negative life-events or personality factors influence cognitive factors (for instance, worrying) which is then linked to elevated risk for anxiety disorders.

Cognitive Approach to Anxiety

Cognitive theories in anxiety often suggested that biases in information processing could play a key role in anxiety disorders (for a review, see van Bockstaele, Verschuere, Tibboel, De Houwer, Crombez, & Koster, 2014). One of the most influential cognitive approaches in anxiety is proposed by Beck and Clark (1997); *three-stage schema-based information processing model*. According to this model, anxiety is related to information processing biases at several stages. Firstly, anxious individuals are more sensitive to threat-related information; hence, they allocate greater attention to such information (stage 1). After allocation of attention to threat, *primal threat mode* is activated (stage 2). This stage mainly serves survival purposes and includes affective, behavioral, cognitive and physiological responses to enhance safety, reduce danger, and cope with threat (i.e. hypervigilance). Primal threat mode then leads to the final stage *secondary elaboration* where coping strategies are evaluated (stage 3). This stage is usually slow, effortful and maladaptive for anxious individuals (i.e. worrying). Recently, this dominant model was revised and extended, and “increased threat expectancies” were brought up as a key (causal) underlying component able to account for abnormal threat-related information processing in anxiety, as well as impaired value processing more generally (Grupe & Nitschke, 2013).

Another important cognitive model in anxiety is proposed by Williams, Watts, MacLeod, & Mathews (1988). This model has examined the cognitive mechanisms underlying vulnerability for anxiety and tried to explain why anxious individuals are characterized by biases during information processing. They suggest that high state anxiety, a transient emotional state of tension and apprehension (Spielberger, 1972), biases the automatic affective evaluation of the threat value of incoming stimuli (*affective decision mechanism*). Hence, high state anxious individuals are more likely to evaluate the threat value of a stimulus as high. If the stimulus is perceived as threatening, *resource allocation mechanism* gets activated depending on the level of trait anxiety, a personality trait referring to individual differences in proneness to anxiety (Spielberger, 1972). Individuals high in trait anxiety, have a tendency to subsequently orient attention to threatening stimuli. Low trait anxious individuals, on the other hand, keep their attention away from such stimuli.

Willams et al.'s model (1988) has been criticized based on the notion that only high anxious individuals would have a stable bias to orient towards threatening information. However, consistently orienting attention away from the source of threat and completely ignoring it probably would be problematic since orienting to potential danger is important to attain safety. Considering this critical point, Mogg and Bradley (1998) proposed another cognitive model. According to the *cognitive-motivational model* by Mogg and Bradley (1998), attentional resources are also allocated to a negative stimulus depending on threat value. Threat value of a stimulus is evaluated via the *valence evaluation system*. Depending on the perceived threat value, the so-called *goal engagement system* gets activated. If the stimulus is perceived as highly threatening, the *goal engagement system* will lead to prioritized processing of this stimulus and attentional resources will be allocated to it. Importantly, this model proposes that high trait anxious individuals have a tendency to overestimate threat during *valence evaluation*. Therefore, high trait anxious individuals direct their attention to negative stimuli even when the actual threat value is deemed only mild. However, low trait anxious individuals attend to threat only when the actual threat value is high.

The theories mentioned so far emphasize the role of information processing biases with regard to threat-related stimuli specifically. However, effects of anxiety on information processing can be observed even in the absence of threat (see Grupe & Nitschke, 2013). For example, the hypervigilance theory by Eysenck (1992) proposes that anxious individuals have a general tendency to scan their environment widely since they are vigilant for any possible threat. Therefore, they can be sensitive to any kind of distractor (whether it is threat-related or not). This theory also suggests that the influence of high trait anxiety can be observed mainly when state anxiety is also high. In a related matter, Eysenck and Calvo (1992) proposed the processing efficiency theory. This theory makes a distinction between processing efficiency which refers to the cognitive effort invested to accomplish a task (i.e. the manner in which the cognitive resources are allocated towards a desired outcome) and performance effectiveness which refers to the quality of performance (outcome, i.e. accuracy rates). According to the processing efficiency theory, anxiety typically impairs processing efficiency rather than performance effectiveness. This is observed especially under stressful conditions (i.e. while performing a challenging task). More specifically, this theory proposes that high trait anxiety leads to elevated worry (often regarded as a cognitive component of anxiety; Mathews, 1990) and due to elevated worry occupying limited cognitive resources, anxious individuals show impaired processing efficiency. However, the processing efficiency theory does not take the influence of neutral or emotional distractors into account and this theory also does not specify which cognitive mechanisms are influenced by anxiety.

Considering the limitations of the processing efficiency theory (Eysenck & Calvo, 1992), Eysenck, Derakshan, Santos and Calvo (2007) proposed the attentional control theory. The attentional control theory posits that anxiety disrupts the balance between attentional systems (top-down, goal-driven system vs bottom up, stimulus-driven system; Corbetta & Shulman, 2002; Bishop, 2007), and as such anxiety impairs attentional control by reducing processing efficiency. Furthermore, according to this theory, anxiety-related impairments in attentional control are observed even more in the presence of a threat-related distractor; yet high anxiety is also associated with impairments in core cognitive mechanisms like attentional control (Pacheco-Unguetti, Acosta, Callejas, & Lupiáñez, 2010; Bishop, 2009) and working memory (WM; Qi, Chen, Hitchman, Zeng, Ding, Li & Hu, 2014a; see also Berggren & Derakshan, 2013 for a review) even in the absence of threat.

Considering these prominent cognitive views and theoretical approaches in anxiety, this dissertation mainly focused on anxiety-related biases as well as impairments in information processing as vulnerability to anxiety. Our main aim was to gain a greater understanding of cognitive risk factors of anxiety at the behavioral and neurophysiological levels. In the following sections, we will describe the key constructs under investigation in the current thesis (i.e., WM and attentional control mechanisms). Finally, we present an overview of the empirical chapters that form the bulk of this thesis.

WORKING MEMORY

WM is a limited capacity cognitive storage system which is essential to perform complex tasks (Baddeley, 1992). According to Baddeley (2003), WM has four main sub-systems: a phonological loop (for processing verbal information), a visuospatial sketchpad (for processing visual-spatial information), an episodic buffer (for the integration of information between WM components and also linking WM to long term memory), and a central executive (executive control of attention and information processing; Baddeley, 2003).

In many situations, information not only needs to be kept online in order to successfully complete a given task, but it has to be timely altered and updated to meet specific task demands. A key construct in this literature is the notion of WM capacity (as opposed to short term memory “span” only). Capacity of WM is explained in terms of one’s ability to process task-relevant information and resist distractor interference (Shipstead, Harrison, & Engle, 2012). In order to explain individual differences in WM capacity, three broad mechanisms are suggested (Shipstead, Lindsey, Marshall, & Engle, 2014) – namely; primary memory (for storage and maintenance of task-relevant information in WM); attention control (ability to remain focused on goal-relevant information); and secondary memory (for retrieving information).

Among the components of WM and processes contributing to WM capacity, the central executive/attentional control is often associated with anxiety-related impairments (Eysenck & Calvo, 1992; Eysenck et al., 2007). Therefore, we describe hereafter this mechanism more extensively, considering its clear and strong relationship with anxiety.

Sub-functions of Central Executive

The central executive sub-system of WM has three main functions – namely; (1) inhibition, (2) shifting, and (3) updating WM (Miyake, Friedman, Emerson, Witzki, Howerter, & Wager, 2000). **(1) Inhibition function** is defined as an ability to actively ignore or suppress task-irrelevant while focusing on task-relevant information (Kok, 1999; Miyake et al., 2000). **(2) Shifting function** is defined as an ability to switch between two cognitive tasks flexibly (Monsell, 1996). Lastly, **(3) Updating function** is defined as an ability to actively monitor and update task-relevant information (Morris & Jones, 1990).

Anxiety has been related to inefficient processing of all these sub-functions (see Berggren & Derakshan, 2013 for a review). The influence of anxiety on these functions is further described in the next sections.

WORKING MEMORY IN RELATION TO ATTENTIONAL CONTROL AND ANXIETY

Attentional Control

WM processes are strongly associated with attentional control (Baddeley, 2003; Gazzaley & Nobre, 2012; Shipstead et al., 2014). Accordingly, inefficient recruitment of attentional control can also lead to inefficient functioning of WM. Efficient processing of attentional control relies on the interaction between two sub-systems of attention: Bottom-up system and Top-down system (Corbetta & Shulman, 2002; Theeuwes, 2010; see also Posner & Petersen, 1990). The bottom-up attentional system is stimulus-driven and reflexive. It is easily influenced by novel, salient stimuli in the environment (such as threat-related stimuli). By comparison, the top-down attentional system is goal-directed and volitional. It relies on experience, knowledge and ongoing task goals. According to Corbetta & Shulman (2002), when a salient (or emotionally laden) stimulus is detected, the bottom-up attention system “breaks in” and interrupts activity of the top-down attention control one (see also Uddin, 2015).

The interaction between top-down and bottom-up attentional systems is crucial since it determines to what extent individuals are able to inhibit interference by a potential threat and remain focused on their current goals (Pashler, Johnston, & Ruthruff, 2001; Barrett, Tugade, & Engle, 2004). Furthermore, anxiety is an important factor which can greatly influence the balance between the top-down and bottom-up systems (Eysenck et al., 2007; Bishop, 2007). In the following section, we start by describing the top-down factors and their relationship to anxiety, followed by a description of bottom-up factors related to anxiety. We end this section by describing how the context, which is defined here as the amount of ongoing cognitive tasks, also influences the balance between bottom-up and top-down processing in relation to anxiety.

Top-down influences: Attentional Control and Working Memory

The balance between top-down and bottom-up attentional control might be highly influenced by a distracting stimulus since such stimulus may enhance bottom-up processing while depleting top-down control. This is often the case with high anxious individuals especially when there is a threat-related distractor (Bishop, Duncan, Brett, & Lawrance, 2004; Bishop, 2007), supporting the view of increased attentional bias towards threat in anxiety at the expense of top-down attention control (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van IJzendoorn, 2007). Furthermore, recent theoretical accounts propose that high trait anxiety might be related to general deficits in attentional control regardless of the presence of threat in the environment (see Eysenck et al., 2007; Berggren & Derakshan, 2013 for reviews). Specifically, high trait anxiety has been associated with deficits in top-down attentional control (Pacheco-Unguetti et al., 2010; Bishop, 2009).

Anxiety-related impairments in attentional control can be observed through the central executive and its three functions (Eysenck et al., 2007); inhibition, shifting and updating (Miyake et al., 2000). Early theoretical accounts suggested that effects of anxiety on updating function can be weaker compared to shifting and inhibition functions since updating might be more related to the storage of necessary information rather than attentional control per se (Eysenck et al., 2007; Eysenck & Derakshan, 2009). However, recent developments in this area indicated that updating function is also influenced by anxiety, though impairments in this function might be observed more clearly at a neurophysiological rather than purely behavioral level (i.e. Qi et al., 2014a). Furthermore, it should also be noted that although these three sub-functions of central executive are dissociable, they are all highly correlated with each other (Miyake et al., 2000).

Studies concerning the role of anxiety in inhibition, shifting and updating are presented below:

(1) Inhibition

Anxiety is associated with difficulties in filtering out or suppressing task irrelevant information. This has been investigated in several studies using various tasks such as: a matching task where participants need to decide if two stimuli are the same while ignoring task-irrelevant negative information (Bishop, Duncan, Brett, & Lawrence, 2004); a visual search task where participants need to focus on the shapes and detect the target while ignoring the colors of the shapes (Moser, Becker, & Moran, 2012); a change detection task where participants need to focus on certain stimuli and monitor whether specific features of these stimuli have changed or not while ignoring task irrelevant stimuli (Qi, Ding, & Li, 2014b; Stout, Shackman & Larson, 2013; Stout, Shackman, Johnson, & Larson, 2015) and an antisaccade task where participants need to look away from target stimuli and suppress it (antisaccade) or simply look at the target stimuli (prosaccade) depending on the instructions (Derakshan, Ansari, Hansard, Shoker, & Eysenck, 2009; Ansari & Derakshan, 2011a). All these studies showed that elevated trait anxiety (at the sub-clinical level) is related to greater difficulties in performing the task efficiently while ignoring task-irrelevant information.

(2) Shifting

High anxious individuals have also greater difficulties when they need to switch between two different tasks and use their attention flexibly. For example, this has been demonstrated via an arithmetical task where participants need to switch between addition/subtraction or multiplication/division (Derakshan, Smyth, & Eysenck, 2009) and a mixed antisaccade task where participants need to look at the stimuli (prosaccade) or look away from the stimuli (antisaccade) depending on the cue shown prior to each trial/target (Ansari, Derakshan, & Richards, 2008; Ansari & Derakshan, 2011b).

(3) Updating

High anxiety is also associated with impairments in monitoring and updating task-relevant information. This has been shown via a modified flanker task where participants need to perform two different tasks simultaneously (Qi, Zeng, Luo, Duan, Ding, Hu, & Li, 2014c). In this task, participants need to identify the orientation of a target arrow in the middle while ignoring the distracter arrows around it (task 1). Meanwhile, they need to remember one (low load) or six (high load) letters which are presented at the beginning of each trial (task 2). In this study, Qi et al. showed that anxious individuals have difficulties performing the task especially under high load when the task is more demanding. Another study, using a change detection task where participants needed to actively monitor the orientation of the certain shapes, showed that high anxious participants utilized their cognitive resources less efficiently as compared to low anxious participants (Qi et al., 2014b).

Bottom-up influences: Attentional Bias towards Threat

The influence of anxiety on cognitive performance is also highly dependent on the negative/threatening/aversive content of a task due to attentional bias towards such stimuli. Attentional bias is defined as a tendency to notice and focus on threatening information in the environment (Bar-Haim et al., 2007). The critical role of attentional bias towards threat on development and maintenance of clinical anxiety is also highlighted in many cognitive theories in anxiety (MacLeod, Mathews, & Tata, 1986; Eysenck, 1992; Williams et al., 1988; Beck & Clark, 2007).

The direct link between attentional bias and anxiety has also been investigated using bias modification techniques (see MacLeod & Mathews, 2012 for a review). In one such study (MacLeod, Rutherford, Campbell, Ebsworthy, & Holker, 2002), a specific attentional bias was induced either towards threat (participants were trained to attend to threat-related stimuli) or away from it (they were trained to attend to emotionally neutral stimuli). In this study, MacLeod et al. (2002) observed that participants with an attentional bias towards threat showed increased vulnerability to a stressor (a difficult anagram task) and elevated anxiety. Results of this study suggest a direct link between attentional bias and vulnerability to anxiety.

As summarized above, the link between anxiety and attentional bias has been well established. Early attentional bias towards threat-related information can also influence a number of cognitive processes at various levels and in different directions. In order to understand the role of attentional bias on information processing in anxiety, it is important to clarify how bias-related influences appear at different stages of information processing under different conditions. The second empirical chapter of this thesis directly examined this question.

Context: Task Load

According to the load theory of selective attention and cognitive control (Lavie, Hirst, de Fockert, & Viding, 2004; Lavie, 2005), the actual influence of distracting information on cognition depends on the type of load experienced at a given moment in time by the subject, with the contrast made between perceptual vs cognitive/WM load in this model. This theory posits that high perceptual load is related to reduced interference by distractors. Accordingly, studies investigating the influence of anxiety on performance considering perceptual load showed increased distractibility in relation to elevated anxiety only under low perceptual load (Bishop, Jenkins, & Lawrence, 2007; Bishop, 2009). However, as opposed to perceptual load, cognitive (WM) load has been related to increased interference by distractors (Lavie et al., 2004). In accordance with this view, the attentional control theory (Eysenck et al., 2007) claims that, if the task is cognitively demanding, adverse effects of anxiety on performance increase (also see Berggren & Derakshan, 2013 for a review). While anxious individuals are performing such a demanding task, the task requirements may use up limited cognitive resources which may otherwise serve for exerting compensatory effort to maintain performance quality (performance effectiveness; Eysenck et al., 2007). Hence, if the cognitive load of a task is high, anxious people can have greater difficulties in performing the task. In line with this view, several studies demonstrated that anxiety was related to greater impairments under high compared to low cognitive load (MacLeod & Donnellan, 1993; Berggren, Koster, & Derakshan, 2012; Qi et al., 2014a; Qi et al., 2014c).

ANXIETY

In this dissertation, we distinguish between several aspects of anxiety based on the previous research in this domain. More specifically, the following aspects of anxiety will be considered: (1) State and trait anxiety; (2) Worry.

State and Trait Anxiety

Classically, the distinction is made between two forms of anxiety: state vs. trait anxiety. The former is defined as a temporal emotional state in response to circumstances perceived as threatening (or uncertain), whereas the latter is defined as a stable individual characteristic pertaining to the proneness to experiencing anxiety (Spielberger, 1972).

As mentioned in the previous sections, there is an extensive literature demonstrating that high trait anxiety is related to information processing biases, impaired attentional control and also reduced WM capacity (see Bar-Haim et al., 2007; Eysenck et al., 2007; Berggren & Derakshan, 2013; Moran, 2016 for reviews). The interaction between state and trait anxiety is also discussed in several theories in anxiety. For example, Williams et al. (1988) proposed that state anxiety is related to the threat value evaluation of a stimulus, while trait anxiety is related to attentional resources allocated to it. Furthermore, Eysenck (1992) proposed that the impact of high trait anxiety on attention is most evident when the level of state anxiety is also high. Accordingly, many studies demonstrated increased attentional bias and interference by threat when both trait and state anxiety levels are high (MacLeod & Mathews, 1988; Richards, French, Johnson, Naparstek, & Williams, 1992; MacLeod & Rutherford, 1992; Egloff & Hock, 2001).

Several studies also investigated the role of trait and state anxiety on performance separately. In such a study, Pacheco-Unguetti et al. (2010) showed that while high trait anxiety was related to impairments in attentional control, state anxiety was related to vigilance (alerting) and context sensitivity (orienting). Bishop, Jenkins and Lawrence (2007) also demonstrated the differential effects of trait and state anxiety on information processing. They observed that state anxiety was related to greater processing of threat-related stimuli (i.e. increased amygdala activity as response to fearful faces), whereas trait anxiety was related to reduced attentional control (i.e. reduced lateral prefrontal cortex activity). These findings suggest that while trait-anxiety is related to more general deficits in attentional control (as manifested mostly by abnormal prefrontal functions), state anxiety is related to vigilance and orienting to salient (i.e. threat-related) stimuli (as expressed by heightened limbic activations, including in the amygdala). Accordingly, several studies have demonstrated that increased state anxiety was related to greater attentional bias towards threat (Fox, Russo, Bowels, & Dutton, 2001; Mathews & MacLeod, 1985; Mogg, Bradley, De Bono, & Painter, 1997). However, anxious mood has also been associated with performance benefits in sustained attention and response inhibition (Robinson, Krimsky, Grillon, 2013; Grillon, Robinson, Mathur, & Ernst, 2015). Furthermore, several studies have demonstrated threat-related stimuli can facilitate subsequent information processing stages (Lystad, Rokke and Stout, 2009) and attentional control (Birk, Dennis, Shin, & Urry, 2011) in relation to elevated state-anxiety.

Several investigations have also focused on more complex cognitive processes such as WM in relation to state anxiety. In these studies, elevated state anxiety has been associated with impaired WM (Lavric, Rippon, & Gray, 2003; Shackman, Sarinopoulos, Maxwell, Pizzagalli, Lavric, & Davidson, 2006; Vytal, Cornwell, Arkin, & Grillion, 2012; Vytal, Cornwell, Letkiewicz, Arkin, & Grillon, 2013). However, these studies assessed WM performance using emotionally neutral tasks, hence, the potential influence of threat-related stimuli on this relationship where state-anxiety can potentially enhance the performance (Lystad et al., 2009; Birk et al., 2011) could not be established. The third empirical chapter of this thesis sought to fill this gap.

The different studies mentioned above with regard to the relationship between state anxiety and WM (such as Vytal et al., 2012; 2013) mainly manipulated state anxiety via threat of shock, which targets mostly the anxious arousal component of anxiety (Robinson, Vytal, Cornwell, & Grillon, 2013). State anxiety also has a worry (anxious apprehension) component (Liebert & Morris, 1967; Heller & Nitschke, 1998) that can be dissociated from its arousal counterpart (Bijsterbosch, Smith, Forster, John, & Bishop, 2014). Studies focusing on worry (both at trait and state level) are explained in more detail in the following section.

Worry Component of Anxiety

Worry is described as a state of having uncontrollable, intrusive, negative thoughts about the future (Borkovec, Robinson, Pruzinsky, & DePree, 1983). It is often referred to as the "cognitive component" of anxiety (Mathews, 1990) and associated with attentional bias towards threat as well as general impairments in attentional control and WM (Eysenck & Calvo, 1992; Eysenck et al., 2007; Mathews, 1990; Hirsch & Mathews, 2012; also see Moran, 2016 for a review).

The relationship between worry and attentional bias towards threat can be bidirectional. Several studies have previously shown that attentional biases towards threat increase vulnerability to worrisome thoughts (Hirsch, MacLeod, Mathews, Sandher, Siyani, & Hayes, 2011; Krebs, Hirsch, & Mathews, 2010); while induced worry also increases attentional bias towards threat (Oathes, Squillante, Ray, & Nitschke, 2010). Furthermore, other studies investigating the influence of worry on WM in the presence of threat-related distractors have shown that trait vulnerability to worry was related to inefficient filtering of threat-related distractors from WM (Owens, Derakshan, & Richards, 2015; Stout, Shackman, Johnson & Larson, 2015).

Adverse effect of worry on attentional control and WM can also be observed in the absence of threat-related stimuli shown in the environment. According to several cognitive theories of anxiety (Processing efficiency theory, Eysenck & Calvo, 1992; Attentional control theory, Eysenck et al., 2007), worry uses up the limited attentional resources leading in turn to reduced capacity of WM. Accordingly, several studies investigating the role of induced worry in attentional control have demonstrated worry-related deficits suggesting worry consumes the cognitive resources which would otherwise be available for optimal attentional control (Hayes, Hirsch, Mathews, 2008; Leigh & Hirsch, 2011). Furthermore, similar results were also observed in a sample of patients with generalized anxiety disorders (GAD; Stefanopoulou, Hirsch, Hayes, Adlam, & Coker, 2014) which are characterized by pathological worry (Borkovec & Inz, 1990; Mathews, 1990; Wells, 1995; Hirsch & Mathews, 2012; Grupe & Nitschke, 2013).

In spite of the wealth of research concerning the relationship between worry and WM, there are still several open issues regarding the actual role of WM capacity. Theoretical accounts of worry (Hirsch & Mathews, 2012; Eysenck et al., 2007) suggest that worry lowers or shrinks WM capacity. However, to the best of our knowledge, there has not been any study yet investigating the direct link between worry and WM capacity. Hence, the fourth empirical chapter of this thesis focused on this question by manipulating/inducing worry in order to titrate its possible (interference) effects on WM capacity directly. Furthermore, high WM capacity is associated with greater attentional control and the ability to inhibit task irrelevant distractors better (Barrett et al., 2004). Hence, high WM capacity may also potentially reduce worry-related impairments in the presence of distractors. Accordingly, in the fifth empirical chapter of this thesis, we dwelt on this question and focused on the putative greater impact worry can have on WM when threat-related distractors come into play (i.e. Stout et al., 2015). Presumably, these investigations can be helpful in order to gain a better understanding of the complex relationship between worry and WM.

THESIS OUTLINE

Considering (cognitive) theories of anxiety and cognitive vulnerability factors to anxiety disorders (Eysenck, 1992; Eysenck & Calvo, 1992; Beck & Clark, 1997; Mogg & Bradley, 1998; Mathews & MacLeod, 2005; Eysenck et al., 2007), the general aim of the current thesis is to examine modulatory effects of anxiety on core cognitive mechanisms such as attentional control and WM, when this affective variable is conceived either as a trait or a state. Within this broad aim, several aspects of our approach deserve specific consideration. We will apply (1) a multi-method approach including behavioral as well as neurophysiological tasks; (2) focus on specific subcomponents of anxiety; (3) focus on causal effects, whenever possible.

(1) Multi-method approach

Anxiety-related effects on attentional control and WM are not always detected in the mere quality of performance (performance effectiveness; i.e. accuracy rates) since anxiety is more likely to have an impact on processing efficiency (i.e. cognitive effort; often investigated via indirect neurophysiological measures; Eysenck & Calvo, 1992; Eysenck et al., 2007). In line with this assumption, some earlier studies have already demonstrated that high anxious individuals have reduced WM capacity (Qi et al., 2014a) and inefficient filtering of task-irrelevant information from WM (Qi et al., 2014b), as evidenced at the neurophysiological (EEG) level, while no behavioral differences were observed in these studies as a function of anxiety. According to the attentional control theory of anxiety (Eysenck et al., 2007), anxious individuals might be utilizing some kind of puzzling compensatory strategies in order to keep up with the desired performance outcome (Derakshan & Eysenck, 2009; Berggren & Derakshan, 2013), a strategy which may in turn deplete processing efficiency in a non-transparent way. Dovetailing with this view, several studies have previously shown that anxious individuals exert greater cognitive effort at the neurophysiological level, while no behavioral differences were actually observed in relation to anxiety (Righi, Mecacci, & Viggiano, 2009; Ansari & Derakshan, 2011a; Basten, Stelzel, & Fiebach, 2012). Hence, to address this issue and the likely dissociation in the expression of effects exerted by anxiety on cognition (with positive evidence at the neurophysiological level but no such clear translation into behavioral performance), we conducted a series of studies using both behavioral and neurophysiological (EEG) measures in this work (see **chapters 2 and 6**).

(2) Components of anxiety

As we have already touched upon here above, anxiety can be decomposed into several aspects/non-overlapping components (albeit with a high degree of collinearity), including trait anxiety, state anxiety, and worry. Each of these three components has different effects on functioning and performance and might, therefore, be differentially related to cognitive processes. Although these components of anxiety are interrelated, we aimed to investigate the cognitive processes associated with each of them. Hence, across the different empirical chapters gathered in this thesis, different components of anxiety were scrutinized, including trait anxiety (**chapter 2 and 6**), state anxiety (**chapter 3**), and worry **(chapter 4 and 5)**.

(3) Causal influences

Most of the existing studies in this domain are of cross-sectional nature, where the focus is usually put on establishing the existence of a possible link between anxiety and (specific) cognitive processes, mostly using correlation or regression analyses. Although this is undoubtedly a valuable approach, such cross-sectional data do not allow to infer whether specific cognitive processes (and more specifically their abnormal or impaired implementation) actually exert a causal influence on (the development and maintenance of) anxiety. In order to examine the potential causal role of attentional control on anxiety, alternative experimental procedures are needed that are suited to experimentally impair or improve attentional control in order to be able to gauge their effects on anxiety. In order to address the question of causality, we examined in **chapter 6** the effects of a novel method meant to improve attentional control in subjects at risk for anxiety (disorders), with the possibility offered then to assess how this improvement causally reduced anxiety in these participants.

A more detailed description on how various components of anxiety are related to attentional impairments and attentional bias is presented below where we outline the specific goals of each empirical chapter included in this thesis.

Chapter 2

The specific influence of attentional bias on performance sometimes appears as benefit (Lindstorm & Bohlin, 2011; Sessa, Luria, Gotler, Jolicœur, & Dell'Acqua, 2011), but sometimes as cost in processing speed or accuracy at the behavioral level (Kensinger & Corkin, 2003; Dolcos & McCarthy, 2006; Iordan, Dolcos, & Dolcos, 2013). This discrepancy likely depends on specific task characteristics such as (1) the relevance of negative information to the task (or the lack thereof) and (2) the actual task load (that can be low or high):

(1) When the negative content is task-irrelevant, it may serve as distractor and lead in turn to impairments in task performance (Pessoa, 2009; Dolcos, Iordan, & Dolcos, 2011). However, when the negative content is task-relevant, it may “paradoxically” lead to performance benefits (Pessoa, 2009; Dolcos & Denkova 2014).

(2) If the perceptual load of the task at hand is deemed high, the interference effect of distractors can be reduced, whereas when the cognitive load of the task at hand is high, the distractor’s effect can be increased (Lavie et al., 2004).

Individual differences in levels of (either trait or state) anxiety can be another source contributing to modulating the complex relationship between attentional bias and performance, due to the strong link between anxiety and attentional bias towards threat (Bar-Haim et al., 2007). Furthermore, early attentional biases to threat can influence further stages of information processing but the actual nature and direction of this effect still remain unclear. Hence, in **chapter 2**, we focused on the role of anxiety in encoding threat-related stimuli into WM at several stages of information processing (with the contrast between early/sensory vs. late/post-perceptual stages of information processing). Since the influence of anxiety on performance is highly dependent on task demands (i.e. greater anxiety-related impairments are usually observed under high WM load; Qi et al., 2014a), the role of task load (high vs low WM load) was also considered.

In this study, we used a change detection task (Vogel, McCollough, & Machizawa, 2005) with faces where the emotional expression (fearful vs neutral) and

WM load (two faces-low load vs four faces-high load) were manipulated using a factorial design. Several studies assessing the role of anxiety on WM previously found anxiety-related impairments at the neurophysiological/EEG level without any clear behavioral differences; however (Qi et al., 2014a; 2014b) suggesting that these two measures (EEG vs. behavior) may be differentially sensitive to effects exerted by anxiety. Hence, in addition to standard behavioral indices (such as speed and accuracy), we also recorded event related potentials (ERPs).

In this study, we expected that increased task demands (high WM load) would reduce processing efficiency and anxiety would modulate this effect. Furthermore, anxiety would be related to greater attentional bias towards threat, which would also have an influence on later stages of information processing (as captured by modulation of late ERP components).

Chapter 3

Earlier studies focusing on the relationship between state anxiety and WM have indicated anxiety-related impairments in WM (Lavric et al., 2003; Shackman et al. 2006), especially under low cognitive load when the task is less demanding (Vytal et al., 2012; 2013). However, these studies assessed WM performance using emotionally-neutral tasks, while other studies have demonstrated that state anxiety actually leads to performance benefits in attention in the presence of threat-related information (Lystad et al., 2009; Birk et al., 2011). Hence, effects of state anxiety on WM processes appear to depend on the presence of threat-related information, although this is still a matter of debate in the literature. **Chapter 3** focused on the role of state anxiety on working memory considering crucial factors which may strengthen this relationship: emotion (threat-related vs. neutral stimuli) and cognitive load (high vs. low load).

In this study, state anxiety was induced using threat of shock. Participants performed a WM task after this anxiety induction. In this task, load and emotion were manipulated using a dual task design. Participants had to perform a number recognition task where they needed to remember 5 two-digit numbers (high load condition - any two-digit numbers, i.e. 39, 43, 22, 18, 76; low load condition – two-digit multiples of ten , i.e. 30, 10, 90, 60, 80). Between consecutive trials (number recognition task), they also had to perform a (secondary) one-back task. During this task, participants were shown two images (both neutral or both fearful) and asked to decide if these pictures were the same or not.

In this study, we expected to observe modulatory effects of anxiety on performance in relation to emotion and cognitive load. Since previous findings already indicated impaired WM in relation to state anxiety (i.e. Shackman et al., 2006), but also performance benefits in the presence of threat-related stimuli (i.e. Lystad et al., 2009), we did not have strong predictions with regard to the actual direction of these effects, however. Hence, exploratory analyses were conducted investigating the role of state anxiety on performance with regard to load and emotion.

Chapter 4

In **chapter 4**, we focused on the role of the worry component of anxiety on WM. Worry is defined as the "cognitive" component of anxiety (Mathews, 1990) occupying limited attentional resources and leading to impairments in WM (Eysenck et al., 2007). Worry-related impairments in attentional control and WM have been studied quite extensively in the past (see Hirsch & Mathews, 2012 for a review). However, the direct link between worry and impairments in WM capacity (individual differences in the functioning of WM; Shipstead et al., 2015) has not been fully examined yet. **Chapter 4** sought to address this issue.

In this study, participants were assigned either to worry or control (not-worry/neutral) condition. Participants in the worry condition were instructed to focus on a personally-relevant worrying subject, while participants in the control condition were instructed to focus on a personally-relevant positive subject (cf. Hayes et al., 2008). In order to investigate the direct effect of worrying on WM capacity, participants performed a WM task (a change detection task with neutral stimuli; Vogel et al., 2005) before (pre-manipulation) and after worry/control manipulation (post-manipulation).

In this study, we surmised that participants who worried would have reductions or attenuated improvements in WM capacity at post vs. pre-manipulation, as compared to participants who did not worry on negative content.

Chapter 5

In **chapter 5**, we investigated the influence of worry on selective attention to threat considering the influence of WM capacity on this relationship. Worry is usually related to threat-related biases in information processing (Hirsch & Mathews, 2012). However, high WM capacity is associated with better attentional control (Barrett et al., 2004) and it may also potentially reduce impairments in performance due to attentional bias towards threat. Accordingly, this study was designed to examine the possible relationship between worry, WMC and attentional bias towards threat.

More specifically, in this study, participants first performed a WM task (a change detection task with neutral stimuli; Vogel et al., 2005) from which we could obtain WM capacity scores. They were then assigned either to a worry or control condition. After worry/control manipulation (cf. Hayes et al., 2008), participants performed a visual search task (i.e. Öhman, Flykt, & Esteves, 2001) with happy, angry and neutral faces where they needed to focus on a face with a certain emotional expression (target face) while ignoring the other ones (crowd; e.g. happy faces surrounding an angry one serving as target, or the other way around).

We hypothesized that participants in the worry condition would show a greater threat-related attentional bias during the subsequent visual search task compared to the control condition (without worry induction). However, we also hypothesized that WM capacity would moderate the relationship between worry and attention selection (visual search task). Specifically, higher WM capacity was expected to be related to a smaller attentional bias towards threat in the worry condition.

Chapter 6

Due to the utmost importance of WM in a wide range of cognitive functions and abilities (i.e. general fluid intelligence; Kane, Hambrick, & Conway, 2005), recently training programs targeting WM have attracted a lot of interest (Jaeggi, Buschkuehl, Jonides, & Perrig, 2008; Buschkuehl & Jaeggi, 2010; Shipstead, Reddick, & Engle, 2012). Some of these studies have found training-related gains on WM capacity (Harrison, Shipstead, Hicks, Hambrick, Redick, & Engle, 2013), cognitive control (Schweizer, Grahn, Hampshire, Mobbs, & Dalgleish, 2013; see Morrison & Chein, 2010 for a review) and general fluid intelligence (see Au, Sheehan, Tsai, Duncan, Buschkuehl, & Jaeggi, 2015 for a review; but see also Harrison et al., 2013; Shipstead et al., 2012). Furthermore, WM trainings have also been applied in sub-clinically/clinically depressed population. Interestingly, these earlier investigations showed increased filtering efficiency (Owens, Koster & Derakshan, 2013); decreased rumination levels (Siegle, Price, Jones, Ghinassi, Painter, & Thase, 2014); and reduced depressed mood (Calkins, McMorran, Siegle, & Otto, 2015) as function of (WM) training. However, effects of WM training in anxious population have not been investigated in detail yet. Nevertheless, such training paradigm might be helpful to investigate the causal status between anxiety and impaired attentional control and WM. Accordingly, **chapter 6** of this thesis focused on WM training in a (subclinical) anxious population, with the aim to assess whether this approach could shield anxious individuals from experiencing high levels of negative affect, worry or rumination.

To guarantee the successful application of the WM training, several requirements usually have to be met (Klingberg, 2010; Shipstead et al., 2012):

(1) Firstly, training should include multiple sessions and take a reasonable amount of time in each session (i.e. 30-40 min, Klingberg, 2010). Furthermore, the training task should be challenging and engaging enough (e.g., adaptive and customized to the actual participant’s performance). The task has to target specific WM operations and should not allow developing alternative strategies (i.e. chunking).

(2) Secondly, the effectiveness of WM training should preferably be assessed via the examination of transfer effects to untrained (and seemingly unrelated) tasks. Hence, there must be pre-training/post-training sessions where untrained tasks (outcome measures) are performed as well. In order to evaluate whether the WM training is effective or not, it is important to have several objective outcome measures at pre-training/post-training sessions each time.

(3) Lastly, there must be an active control condition. For an effective control condition, participants in this condition should also be involved in training somehow. Accordingly, participants in the control condition may either perform a non-adaptive version of the WM training task or another task which is unrelated to WM.

Considering these points, we examined in this study whether an intensive three-week WM training procedure would lead to obvious gains in WM and attentional control in (sub-clinical) anxious subjects. Furthermore, we explored whether training-related gains would be associated with lower anxiety levels.

In this study, pre-selected participants with high level of trait anxiety were assigned either to a training (experimental condition) or an active control condition (control group). For the WM training, the dual n-back task (Jaeggi, Seewer, Nirkko, Eckstein, Schroth, Groner, & Gutbrod, 2003) was used. The dual n-back task has two main components/modalities: visual and auditory. In this n-back task, participants are instructed to indicate whether there is a match between the current trial and a number (*n*) of previous trial in the series either for the visual or auditory information. As the *"n"* increases, the task obviously becomes more difficult, unless training takes place. Therefore, the task can be adaptive to participants' performance. In this study, participants in the training condition performed the adaptive version of the dual n-back task where "n" changed depending on their performance. In contrast, participants in the active control condition performed the non-adaptive version of the task (dual-1-back). Training/active control procedure continued for fifteen sessions spread over three weeks (occurring only during weekdays). Before and after this three-week period, participants were invited to the lab for pre/post testing. During pre/post training sessions, participants performed cognitive tasks assessing attentional control and WM, namely: resting state EEG as an indirect measure/marker of attentional control (cf. Putman, Verkuil, Elsa Arias-Garcia, Pantazi, & van Schie, 2014); a Flanker task (Eriksen & Eriksen, 1974) and an Antisaccade-task (Hallett, 1978) with emotional faces to assess inhibition in relation to emotional stimuli. Furthermore, the Flanker task also had a "stress" condition where participants were exposed to random loud noise bursts in order to examine training-related influences on cognitive control under stressful circumstances. In addition to these tasks, participants also filled in questionnaires regarding anxiety, worry and attentional control.

In this study, we expected to observe training-related gains in cognitive functioning, as assessed via resting state EEG and performance for the Flanker and the Antisaccade tasks. Furthermore, we predicted that these gains might eventually help to maintain lower levels of anxiety.

Chapter 7

In this closing section, we first quickly review and summarize the research goals and main findings obtained in the five different empirical chapters compiled in this thesis. Thereafter, we provide an integrative discussion of these new results, emphasizing their compatibility (or lack thereof) with current and past cognitive models of anxiety available in the literature (as introduced earlier here above in this section). Lastly, the limitations of our studies and future directions for (cognitive neuroscience) research in this area are outlined.

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CHAPTER 2

PROCESSING EMOTIONAL FACES IN RELATION TO WORKING MEMORY LOAD AND ANXIETY: AN EVENT-RELATED POTENTIAL STUDY [1]

ABSTRACT

Attentional bias towards threat is a key characteristic of anxiety (Bar-Haim et al., 2007). This study examined the influence of attentional bias on information processing patterns under varying levels of task load. We used a face change detection task where valence (neutral vs fearful faces) and working memory load (low vs high load) were manipulated. In addition to behavioral indices, we measured ERPs during encoding (N170) and maintenance of information (CNV). We observed a robust load effect on behavioral indexes. N170 activity was modulated by load and anxiety with high anxiety associated with greater N170 under high load. CNV activity was modulated by load, valence, and anxiety with high anxiety associated with lower CNV under high vs low load in the presence of fearful faces. There was a negative association between N170 and CNV in the presence of fearful faces as a function of load which was particularly pronounced in high-anxious individuals. These results suggest a connection between enhanced early processing of fearful faces and recruitment of later cognitive resources in high-trait-anxious individuals.

[1] Sari, B. A., Koster, E. H., & Derakshan, N. (2016). Processing emotional faces in relation to working memory load and anxiety: An event-related potential study. Manuscript submitted for publication.

INTRODUCTION

Cognitive theories of anxiety propose that information-processing biases are a hallmark feature of anxiety and can contribute to the etiology and maintenance of anxiety disorders (Eysenck, 1992; Beck & Clark, 1997). There is an extensive literature showing that the presence of threatening information influences performance especially in high anxious individuals due to an early attentional bias towards such stimuli (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van Ijzendoorn, 2007; Okon-Singer, Hendler, Pessoa, & Shackman, 2015), which in turn influences subsequent more elaborate stages of information-processing. At present, it is not fully clear, through which mechanisms this early attentional bias in anxiety influences later stages of information-processing.

The expression of attentional bias on task performance can vary, sometimes appearing either as benefits (Lindstorm & Bohlin, 2011; Sessa, Luria, Gotler, Joliceur, & Dell 'Acqua, 2011) or as costs (Kensinger & Corkin, 2003; Dolcos & McCarthy, 2006; Iordan, Dolcos, & Dolcos, 2013). Whether an early attentional bias leads to processing benefits or costs likely depends on the task characteristics and goal settings, such as the relevance of threatening information to the task at hand, as well as task load (cognitive/working memory load or perceptual load). With regard to task-relevance, when the threatening information is task irrelevant, it may serve as distractor and thereby cognitive performance on the ongoing task may be impaired (Pessoa, 2009; Dolcos, Iordan, & Dolcos, 2011). However, when threatening information is (directly) task relevant, performance benefits may actually emerge as a result of a more efficient or better encoding of this highly relevant information (Pessoa, 2009; Dolcos & Denkova 2014). According to the load theory of selective attention and cognitive control (Lavie, Hirst, de Fockert, & Viding, 2004; Lavie, 2005), the influence of distracting information on cognition actually depends on the type of load. High perceptual load has been related to reduced distractor interference, whereas high cognitive (working memory; WM) load has usually been associated with the opposite effect, whereby distractors more strongly impair task performance and target processing (Lavie et al., 2004).

Given the strong links between anxiety and attentional bias towards threatening information (e.g., Williams, Watts, MacLeod, & Mathews, 1988), heightened anxiety disposition is thought to influence the effects that threatening information has on cognitive performance as well (Eysenck & Calvo, 1992). According to the attentional control theory of anxiety (Eysenck, Derakshan, Santos, & Calvo, 2007), the presence of threat-related stimuli would more strongly influence WM processes in high anxious individuals. WM is a limited capacity system essential to perform complex cognitive tasks (Baddeley, 1992) and recent evidence suggests that WM processes (such as shifting and updating) are disrupted in anxious individuals when threatening information is presented as distractor (Derakshan & Eysenck, 2009). The current investigation focused on the role of anxiety on encoding threat-related information in WM.

To explore possible modulatory effects of anxiety on the encoding of threatening information under varying conditions of WM load, we used a change detection task (Vogel, McCollough, & Machizawa, 2005) with (emotional) faces, where valence and WM load were manipulated independently. In this task, each trial starts with a complex visual array where participants are instructed to encode specific features of objects presented (memory array). Following this array, a retention interval is presented during which participants need to maintain and rehearse the encoded information. At the end of the retention interval, another visual array appears (test array). Participants are asked to compare this second array to the first one and indicate whether the same objects (with the same features) are presented again or specific features changed between encoding and test (i.e., they have to perform a delayed Match-To-Sample Task, see Goldman-Rakic, 1995; Miller, Erickson, & Desimone, 1996). Previous work using a change detection task with (neutral) shapes showed that high anxious individuals display impaired WM performance in conditions of high WM load (Qi et al., 2014a). In another study, using a modified (emotional) version of the change detection task, Stout, Shackman and Larson (2013) investigated the role of anxiety on filtering efficiency in the presence of threat-related vs. neutral distractors. In that study, Stout et al. (2013) observed impaired filtering efficiency of threat related distractors in high anxious individuals. However, that study investigated the influence of threatening information only when it was used as distractor and therefore, should be ignored. By comparison, much less is known regarding possible modulatory effects of anxiety on WM performance under conditions where the to-be-encoded information is threatening, where either benefits (Lindstorm & Bohlin, 2011; Sessa et al., 2011) or costs (Kensinger & Corkin, 2003) may actually be observed.

In the current study, we focused on behavioral as well as ERP components of WM performance. At the behavioral level our key dependent variables were accuracy levels, sensitivity scores (d prime), and K scores, which provide an index of WM efficiency. At the ERP level, we sought to use markers related to early face encoding as well as maintenance of information in WM to capture early versus later stages of information processing (and their possible modulation by anxiety), respectively. The N170 is an early face-specific ERP component, which typically peaks approximately 150 ms after face onset at occipito-temporal electrodes (Bentin, Allison, Puce, Perez, & McCarthy, 1996). This ERP component is often associated with the structural encoding of faces, as its amplitude is enhanced in response to face stimuli compared to other visual objects that are devoid of a face configuration (Rossion & Jack, 2011). At later stages, for the maintenance of information, we focused on the contingent negative variation (CNV). The CNV is a slow negative wave which appears following a cue (i.e., warning stimulus) and peaks prior to target onset (i.e., imperative stimulus) presentation (Walter, Cooper, Aldridge, McCallum, & Winter, 1964). More specifically, late-frontal CNV has been associated with (cognitive) effort and resource allocation (Leynes, Allen, & Marsh, 1998; Gomez, Flores, & Ledesma, 2007; Brunia, Van Boxtel, & Böcker, 2012).

The main aim of the current study was to gain a better understanding of modulatory effects of anxiety on the encoding (N170) and maintenance (CNV) of threat-related information in WM when two different cognitive load levels (either easy/low load or difficult/high load) were systematically compared to one another. Based on the existing literature (Lavie et al., 2004), we predicted that this manipulation should influence behavioral performance, with decreased efficiency under high compared to low WM load. Importantly, we also surmised that modulatory effects of anxiety on performance in this task would be more evident for high relative to low WM load (Qi, et al., 2014c; Berggren & Derakshan, 2013). Provided that emotional facial expressions are not task relevant in our study (subjects have to focus on the identity of the face stimuli), we did not expect any strong effect of this variable on behavioral performance. However, because anxiety usually biases early stages of information processing when negative emotional information is presented (Fox, Russo, & Georgiou, 2005; Bar-Haim et al., 2007; Eysenck et al., 2007), we surmised that it could influence the early face encoding stage (at the level of the N170). Last, we explored whether the presence of an early attentional bias with anxiety as demonstrated by the amplitude of the N170 could influence later processing stages during WM maintenance, as demonstrated by the amplitude of the CNV.

METHOD

Participants

Twenty-nine university students (7 males) aged between 18 - 38 (*M* = 23, *SD* = 4) were recruited from the University of Ghent. The data of 5 participants were discarded (due to a high artifact rate - over 50% - during the EEG recording). The details of artifact rejection are explained in the data analytic approach section.

Task and Procedure

Face Change Detection Task (Figure 1). Twelve face identities (7 females and 5 males) were selected from the Ekman and Friesen (1976) and Lundqvist, Flykt, and Öhman (1998) databases, each depicting both a neutral or fearful expression. In total 24 face stimuli were used. Each trial started with a fixation cross. After 500 ms, two arrows (pointing either to the left or right) indicated the side of the screen to be attended. Following a variable 200-400 ms SOA, either 2 (low WM load) or 4 (high WM load) faces were presented for 200 ms (memory array – encoding phase). These faces depicted either all neutral or all fearful expressions. After a 2000 ms retention interval, a target display was presented. In half of the trials, the same faces shown during the memory array were presented. In the other half, the identity of one of the faces was replaced by a new one, though the valence of the expression remained unchanged. In these trials, the change occurred only on the cued side (as indicated earlier by the arrows). Participants were asked to perform a delayed match to sample task (i.e., to decide whether the faces shown during the target display were the same or not compared to the faces shown during the memory array).

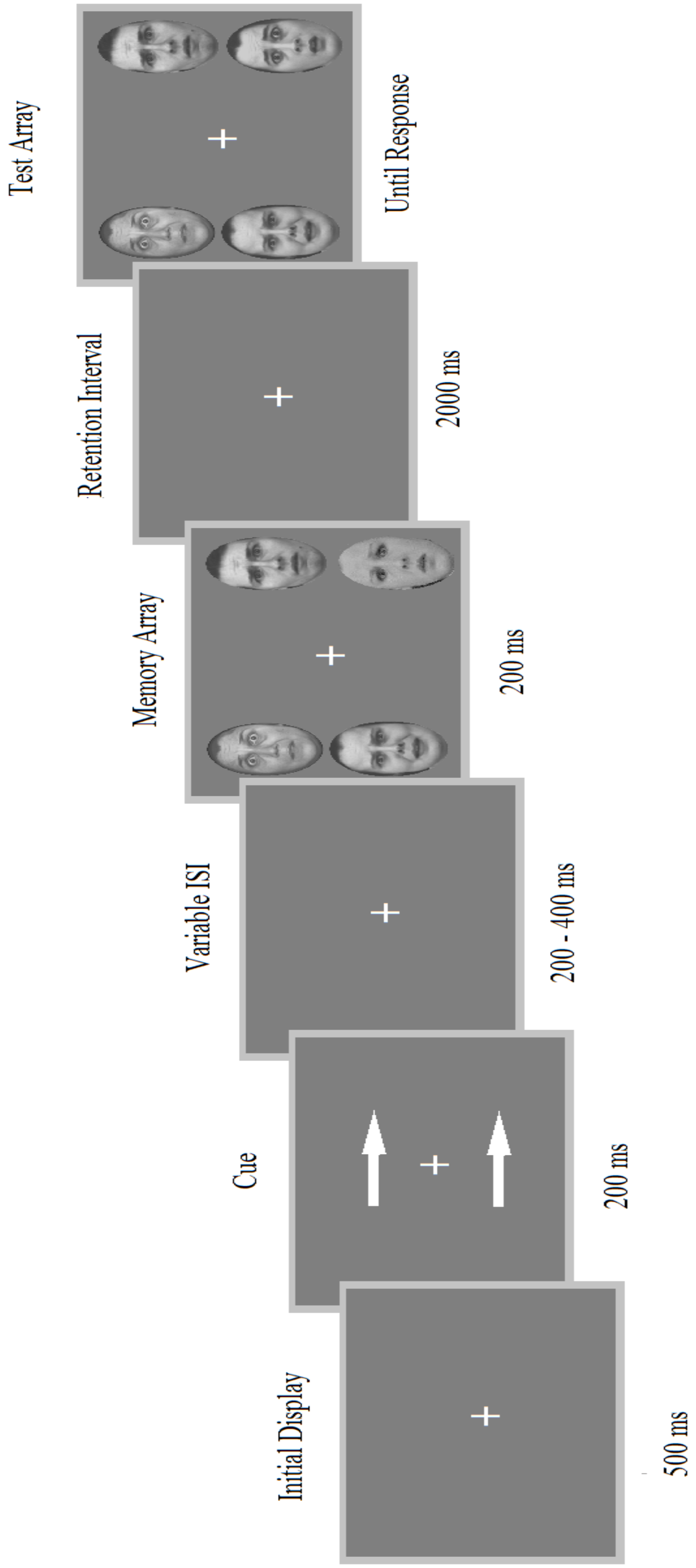
The experimental session included one practice block followed by 8 experimental blocks. In half of these blocks, faces had neutral facial expressions. In the other half, faces had fearful expressions. Emotional expression of the faces was presented block-wise (cf. Li, Li, & Luo, 2006; Sessa et al., 2011) because presentation of negative stimuli in one trial may influence the processing of faces on the subsequent trial (carry-over effects). Hence, by presenting neutral and fearful faces in separate blocks, the influence of emotional expression could be kept stable over time.

The task started randomly with either a neutral or fearful block and continued alternately. The practice block contained 24 trials, while each experimental block included 64 trials. In total, there were 512 experimental trials. However, because of a programming error in the final 2 blocks, only the first 6 (3 neutral and 3 fearful) blocks were included in the analysis for all of the participants.

Procedure

After reading and signing the informed consent form, participants completed self-report questionnaire of trait anxiety (State Trait Anxiety Inventory; STAI-TA; Spielberger, Gorsuch, Lushene, & Vagg, 1983). They were then informed about the EEG procedure and prepared for it. After placement of the electrodes, they were asked to perform the face change detection task. Afterwards, they were paid 30 euro for their participation.

Figure 1. Example of a high WM load – fearful condition in a change trial.



Data Analytic Approach

Behavioral Data. Trials with reaction times faster than 100 ms and slower than 4000 ms were considered as outlier and not included in the analysis. Moreover, only trials within the range of 3 standard deviations from the individual mean were included. After applying these criteria, analyses were performed on 98% of the total data.

To examine WM performance, several indices were calculated on the basis of accuracy scores. First, we calculated sensitivity scores (d prime, Green & Swets, 1974). D-prime scores indicate to what extent participants are sensitive to perceiving face identity changes during this task. Secondly, we calculated WM capacity scores (K score). K scores were calculated by the following formula: $K = S \times (H - F)/(1 - F)$ (Pashler, 1988). In this formula, K represents WM capacity, S is the set size (WM load) to be remembered (1 face or 2 faces), H is the observed hit rate, and F is the proportion of false alarms. Hence, the K-score provides an estimation of the number of faces which can be encoded and held in WM at any one time in the different conditions. K scores may vary between 0-1 for the low WM load (1 face to be encoded- condition) and between 0-2 for the high WM load (2 faces to be encoded-condition).

EEG Data. EEG data were acquired from 64 electrodes placed according to the extended 10-20 EEG system (Biosemi Active Two System). Additional electrodes were placed above and below of the right eye and at the outer canthus of both eyes to monitor vertical and horizontal eye movements, respectively. EEG signals were referenced online to the CMS-DRL ground at a sampling rate of 512 Hz. They were then re-referenced offline to the linked mastoids, using Brain Vision Analyzer 2.0 (Brain Products GmbH, Munich, Germany). Data were then segmented 100 ms pre and 2200 ms post-stimulus onset. The segmented data were corrected for ocular movements using the Gratton, Coles and Donchin (1983) algorithm. Baseline correction was performed before and after ocular correction based on the entire pre-stimulus onset (100 ms). The data were then semi-automatically corrected for the artifacts using an absolute voltage criterion of ±100 µV. Afterwards, individual epochs were averaged separately for each condition (2 emotion x 2 WM load). Noisy channels were interpolated by using a standard spherical splines procedure (Perrin, Pernier, Bertrand, & Echailler, 1989). Lastly, a 30 Hz low-pass filter was applied and grand-average ERP waveforms were created.

We focused on the activity during the retention interval for the correct trials. Specifically, we focused on the CNV component at frontal site which is related to preparatory cognitive effort (Leynes et al., 1998; Wild-Wall, Hohnsbein, & Falkenstein, 2006; Ansari & Derakshan, 2011; Judah, Grant, Mills, & Lechner, 2013). Since CNV typically peaks closer to target presentation over frontal scalp regions (Gomez et al., 2007; Brunia et al., 2012), we exported the mean activity for frontal channels (averaged F1, F2, F3, F4, Fz), 500 ms prior to the target presentation (for the correct trials only). We also focused on N170 to assess early processing of faces and structural encoding (Bentin et al., 1996). We exported the maximal negative peak amplitude within a time-window of 150 to 200 ms for two adjacent right occipito-temporal sites (P8 and PO8), and averaged them.

Analytical Approach. In order to assess the interaction between WM load and emotion, 2 (high vs low WM load) x 2 (neutral vs fearful) ANOVAs were conducted for each of the behavioral outcomes (accuracy rate, K score, d-prime), CNV and N170. Then, in order to understand how these effects were modulated by anxiety, STAI-TA was added as a covariate. If the ANCOVA led to a significant 3 way or 2 way interaction with STAI-TA, it was followed-up by correlational analyses.

For CNV and N170, we calculated difference scores for the correlational analyses by subtracting the mean activity during low WM load condition from high WM load condition (cf. Ruchkin, Canoune, Johnson, & Ritter, 1995; Yang, Wang, Jin, & Li, 2015; Owens, Derakshan, & Richards, 2015). This calculation is useful in order to isolate the ERP components of interest while removing the contribution of other factors, such as motor preparation (Luck, 2005).

Finally, we examined if levels of trait anxiety as measured by the STAI-TA moderated the trajectory between early and late processing of information as indicated by the N170 and CNV components respectively. For this purpose, firstly, correlational analyses were performed between CNV and N170 difference scores for each of the fearful and neutral conditions separately. Significant correlational analyses were followed by moderation analyses with levels of the STAI-TA as moderator of the link between N170 and CNV. We expected that moderation would be found with the N170diff influenced by greater levels of anxiety on the CNVdiff, compared with medium or lower scores. This procedure was performed using IBM SPSS 19 and the macro PROCESS 2.13.2 (Hayes, 2013). Variables were mean centered and controlled for heteroscedasticity.

RESULTS

Behavioral Results

Accuracy. The 2 X 2 ANOVA with WM load (low vs high WM load) x emotion (neutral vs fearful) revealed a significant main effect of WM load, $F(1, 23) = 85.94$, $p < .001$, indicating higher accuracy rate in the low ($M = 82\%$, $SD = 11.40$) as compared to the high WM load condition ($M = 68\%$, $SD = 9.43$). None of the other main or interaction effects were significant, *Fs* < 1, *NS*; see table 1 for descriptive statistics. Including STAI-TA as a covariate, the ANCOVA revealed a significant main effect of WM load, $F(1, 22) = 7.28$, $p = .01$. However, the main effect of emotion and the interaction effects were not significant, all *F*s < 1.7.

D-prime Scores. The 2 X 2 ANOVA WM load (low vs high WM load) x emotion (neutral vs fearful) showed a significant main effect of WM load, $F(1, 23) = 18.20$, $p < .001$, indicating higher scores in the low ($M = 2.29$, $SD = 1.26$) as compared to the high WM load condition ($M = 1.53$, $SD = .87$). Main effect of emotion and the interaction effect did not reach significance, all *F*s < 1, *NS.* Adding STAI-TA as a covariate, no significant main effect or interaction effects were found, *Fs* < 1.1, *NS*; see table 1 for descriptive statistics.

K-Scores. The 2 X 2 ANOVA with WM load (low vs high WM load) x emotion (neutral vs fearful) showed a significant main effect of WM load, $F(1, 23) = 56.08$, $p < .001$, indicating higher scores in the high ($M = 1.23$, $SD = 0.40$) as compared to the low WM load condition ($M = 0.80$, $SD = 0.20$; main effect of emotion and the interaction effect did not reach significance, all *Fs* < 1, *NS*). With STAI-TA as a covariate, the main effect of WM load remained significant, $F(1, 22) = 9.68$, $p < .01$, while the main effect of emotion was not, $F < 1$, *NS*. Interaction effects did not approach significance (WM load x STAI-TA, $F(1, 22) = 1.73$, $p = .20$; WM load x Emotion; $F(1, 22) = 1.31$, $p = .26$; WM load x Emotion x STAI-TA, $F(1, 22) = 1.06$, $p = .32$; Emotion x STAI-TA, $F < 1$, *NS*; see table 1 for descriptive statistics).

Table 1. Mean Accuracy (in percentage), d-prime and K scores for each of Emotion (Fearful, Neutral) and WM Load (High, Low) conditions. *SD*s are reported in parenthesis.

	Low WM Load		High WM Load	
	Neutral	Fearful	Neutral	Fearful
Accuracy	82.47 (11.52)	81.55 (11.88)	68.45 (10.26)	67.54 (10.15)
d-score	2.31 (1.40)	2.27 (1.18)	1.55 (0.94)	1.51 (0.90)
K-score	0.80 (0.21)	0.79 (0.21)	1.26 (0.47)	1.20 (0.44)

EEG Results

N170 (Figure 2). The ANOVA did not show significant main effects of WM load ($F < 1$, *NS*), Emotion ($F(1, 23) = 2.41$, $p = .13$), or an interaction between these two factors ($F < 1$, *NS*). Adding STAI-TA as a covariate, the main effect of load was significant, $F(1, 22) = 10.47$, $p < .01$, indicating slightly larger N170 for the low ($M = -5.67$, $SD = 3.83$) as compared to the high WM load condition ($M = -5.44$, $SD = 4.67$). The main effect of Emotion was non-significant, $F(1, 22) = 1.04$, $p = .32$. Importantly, the interaction between WM load and STAI-TA was significant, $F(1, 22) = 10.22$, $p < .01$. (Interaction effect for Emotion x STAI-TA, $F(1, 22) = 2.10$, $p = .16$; for WM load x Emotion and WM load x Emotion x STAI-TA, all Fs < 1, *NS*).

The significant interaction between WM load and STAI-TA was followed up by correlational analyses. Since Emotion did not modulate this interaction, we averaged N170 amplitudes across the two emotion conditions for the low and high WM load conditions, separately. Next, a difference score was calculated using the following formula: N170diff = N170 for high WM Load – N170 for low WM Load. Elevated negativity on this index indicated larger N170 for the high WM load condition as compared to low WM load condition. We then examined the correlation between

STAI-TA and N170diff. Results revealed a negative relationship between these variables ($r(24) = -.56$, $p < .01$) indicating that higher levels of anxiety were associated with greater recruitment of N170 for the high WM load condition as compared to low WM load condition (Figure 3).

Figure 2. N170 for each of Emotion (Fearful, Neutral) and WM Load (High, Low) conditions for the right – parietal site (averaged P8, PO8). Positive is plotted down. Waveforms were filtered with a high cutoff filter of 5 Hz (slope 24 dB/oct) for visual inspection. The area of interest is highlighted (150 – 200 ms).

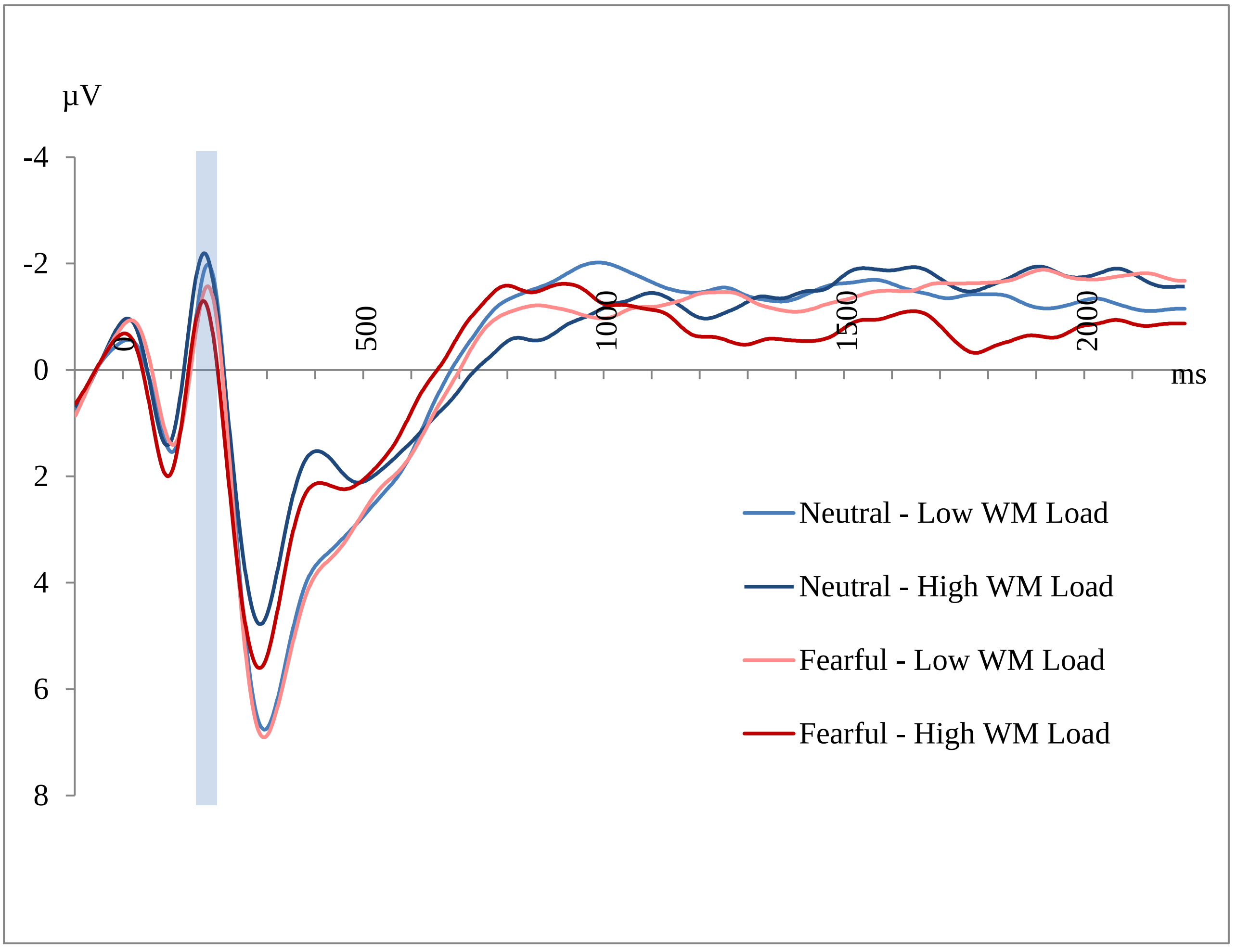
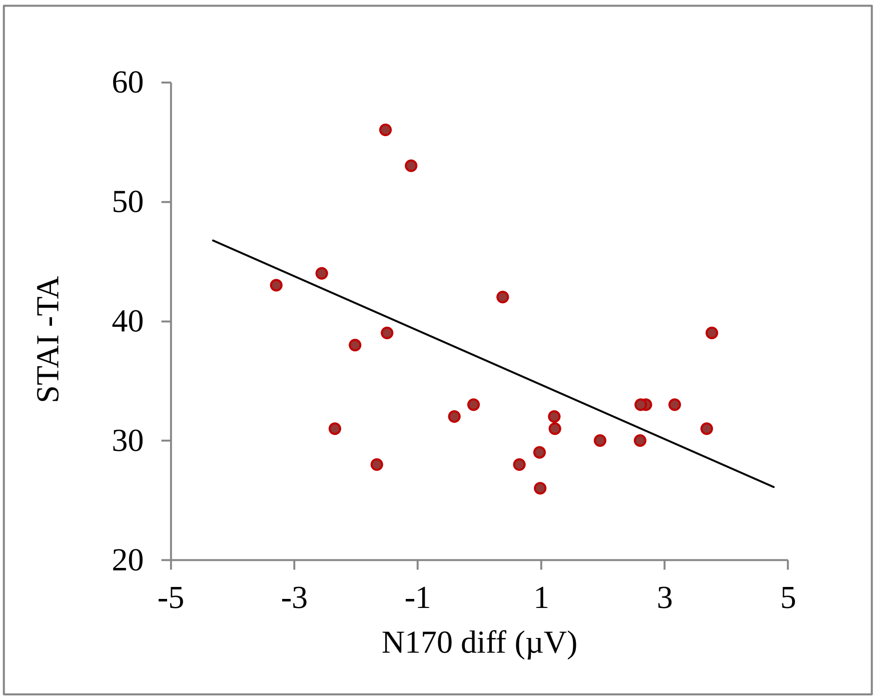


Figure 3. Correlation between difference in N170 activity between high and low WM load (averaged across emotion) and STAI-TA.



CNV (Figure 4). The ANOVA showed no significant main effects of WM load; $F < 1$, *NS* or emotion; $F(1, 23) = 2.96$, $p = .10$. However, there was a significant WM load x Emotion interaction, $F(1, 23) = 5.69$, $p = .05$, indicating larger CNV in the neutral condition as compared to the fearful condition under high WM load (Fearful-high WM load, $M = -0.73$, $SD = 5.65$ vs Neutral-high WM load, $M = -3.60$, $SD = 6.08$; $t(23) = -2.85$, $p < .01$) while such difference was not observed under low WM load (Fearful-low WM load, $M = -2.53$, $SD = 5.29$ vs Neutral-low WM load, $M = -2.18$, $SD = 5.20$; $t < 1$, *NS*).

The ANCOVA with STAI-TA as covariate did not show a significant main effect of WM load ($F<1$, *NS*) or emotion ($F(1, 22) = 1.18$, $p = .29$). The WM Load x Emotion interaction was marginally significant, $F(1, 22) = 3.43$, $p = .08$. Furthermore, there was a significant interaction effect between WM load, Emotion, and STAI-TA, $F(1, 22) = 6.47$, $p < .05$ (all other interactions, Fs < 1, *NS*). The significant three-way interaction was followed up by means of correlation analyses. For that purpose, difference scores were first calculated using the following formula: CNVdiff = CNV for high WM Load – CNV for low WM Load. Elevated negativity on this index indicates larger CNV for the high WM load condition as compared to low WM load condition. This difference score was calculated for each emotion condition, separately.

This analysis revealed a significant positive relationship between STAI-TA and CNVdiff for the fearful condition ($r(24) = .46$, $p < .05$; see Figure 5), but not for the neutral condition ($r(22) = -.19$, $p = .36$), indicating that higher levels of anxiety were associated with greater CNVdiff. Greater CNVdiff implies reduced CNV activity in the high WM load condition as compared to low WM load condition. Hence, this positive correlation indicates high levels of anxiety were related to higher levels of CNV recruited in the low relative to high WM load condition on fearful trials. CNV activity was attenuated under high WM load on fearful trials as a function of high trait anxiety.

In order to investigate whether the correlation coefficient levels between CNVdiff and STAI-TA were different from each other for the neutral and fearful trials, a Steiger test (Steiger, 1980), which is used for the comparison of dependent correlation coefficients, was conducted. This analysis revealed that two correlation coefficients were significantly different from each other; $z = 2.57$, $p < .05$.

Figure 4. CNV for each of Emotion (Fearful, Neutral) and WM Load (High, Low) conditions for frontal site (averaged F1, F2, F3, F4, Fz). Positive is plotted down. Waveforms were filtered with a high cutoff filter of 5 Hz (slope 24 dB/oct) for visual inspection. The area of interest is highlighted (1700 – 2200 ms).

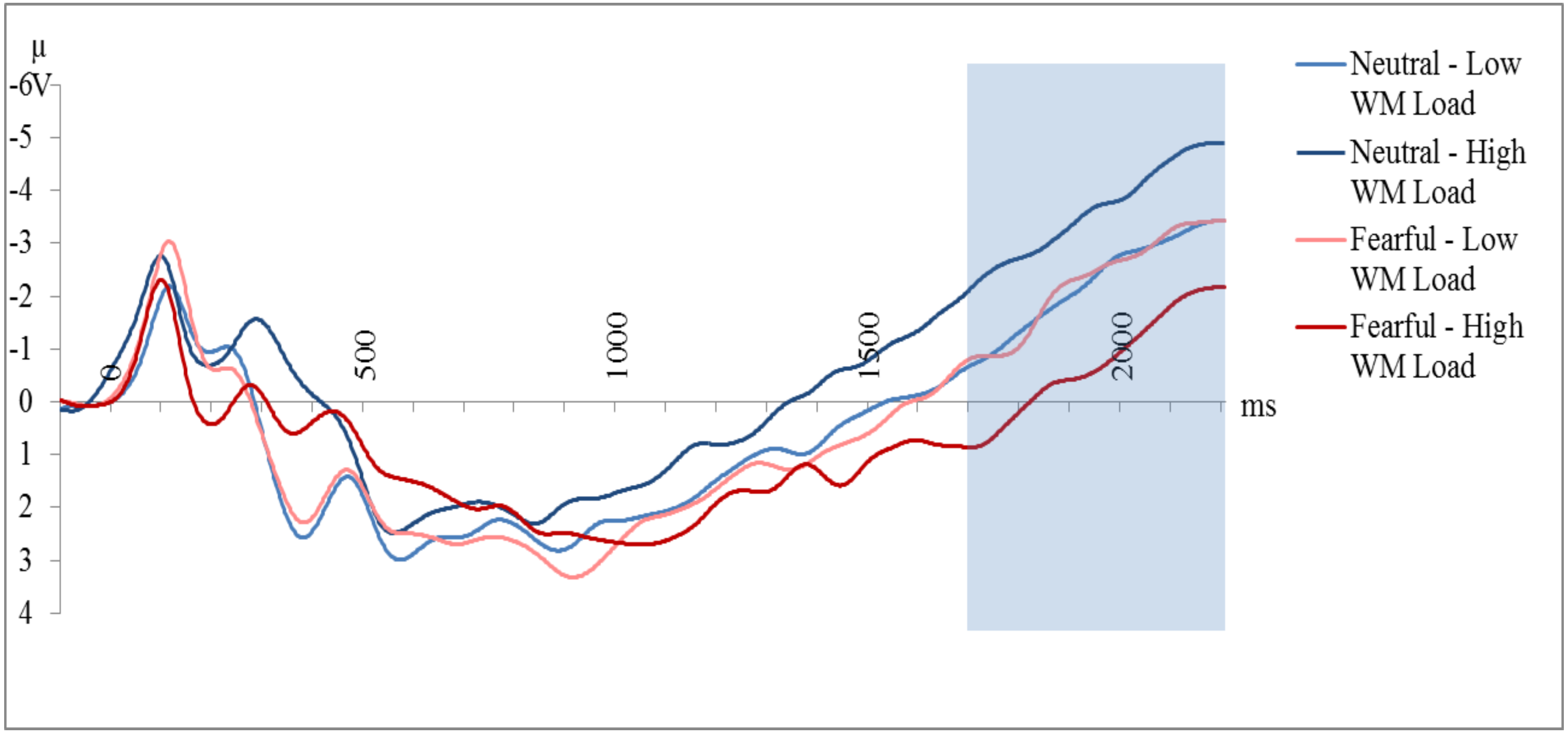
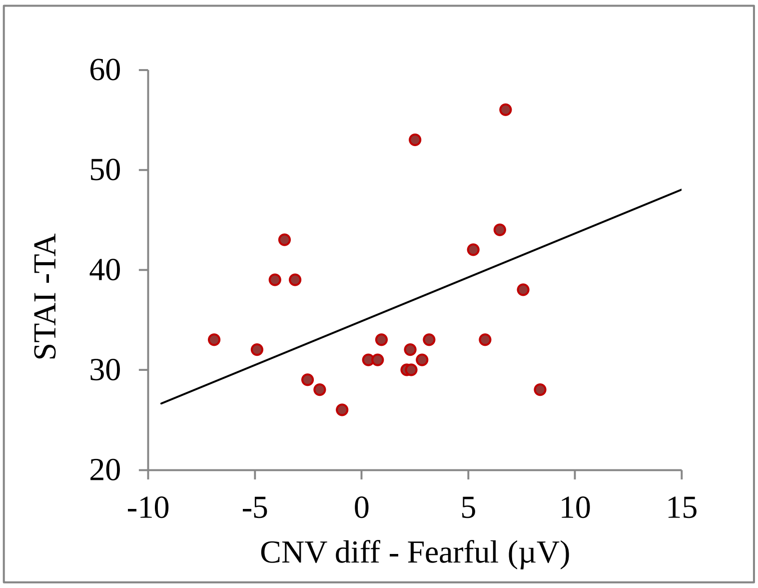
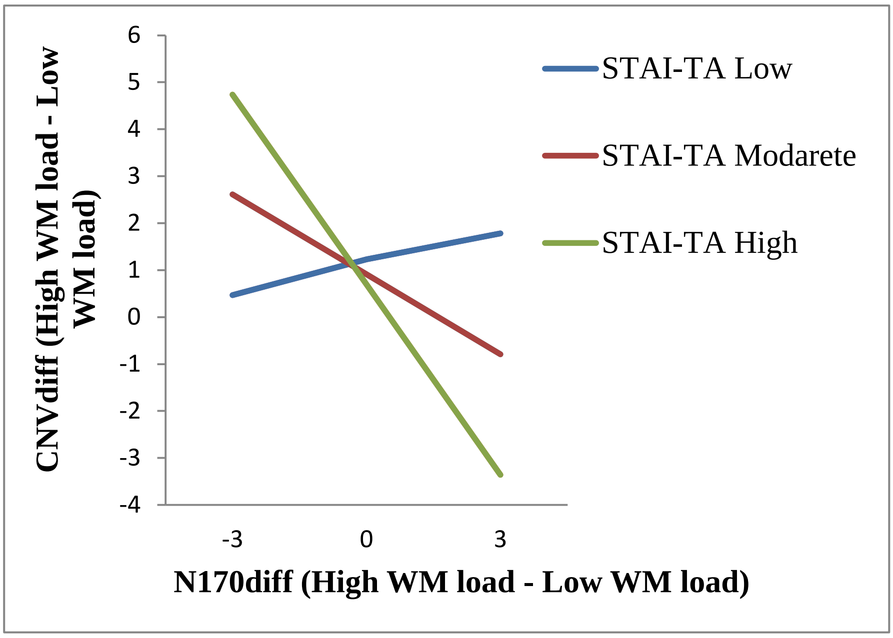


Figure 5. Correlation between difference in CNV activity between high and low WM load for the fearful condition and STAI-TA.



Influences of N170 Activity on CNV Activity Considering Level of Anxiety. There was a marginally significant negative correlation between CNVdiff and N170diff for the fearful trials; $r(24) = -.35$, $p = .09$. Moderation analysis with STAI-TA as moderator and N170diff as the independent variable revealed a marginally significant interaction effect of N170diff and STAI-TA predicting CNVdiff in the fearful condition, $b = -0.081$, $t = 2.02$, $p = .06$. This interaction showed that the N170diff and CNVdiff were negatively correlated at higher levels of trait anxiety, $b = -1.293$, $t = 2.20$, $p < .05$ (figure 6). No moderation was found at medium ($b = -0.542$, $t = 1.75$, $p = .1$) or lower ($b = 0.209$, $t < 1$, *NS*) levels of anxiety. Importantly, correlational analysis between CNVdiff and N170diff for the neutral trials was not significant, $r(24) = .23$, $p = .29$.

Figure 6. Relationship between CNV and N170 for different levels of STAI-TA scores indicating difference in N170 activity between high and low WM load is conversely related to the difference in CNV activity between high and low WM load for high STAI-TA scores (R^2 = .35).



Discussion

The current study focused on anxiety-related information processing biases. Specifically, the role of trait anxiety on the processing of emotional (threat-related) information in WM under different WM load levels was investigated. We predicted that high WM load would require more processing resources, leading to decreased processing efficiency of performance and trait anxiety would modulate this effect. Furthermore, anxiety would be related to biases in early attention towards threat (indexed by the amplitude of the N170) which might also influence retention of material at further stages of processing (indexed by the amplitude of CNV). In this investigation, participants performed a face change detection task where emotional expressions of faces (fearful vs neutral) and WM load (low load vs high load) were manipulated. The main results can be summarized as follows: (1) at the behavioral level there was a clear effect of load but not of emotion or anxiety; (2) at the ERP level, N170 activity was modulated by WM load in relation to anxiety; (3) For CNV activity, there was an interaction between WM load and emotion, which was also modulated by anxiety; (4) there was a trend showing that the difference in the amplitude of the N170 between high and low WM load was conversely related to the difference in the amplitude of the CNV activity between high and low WM load at high levels of trait anxiety suggesting an interplay between early and late information processing in anxiety. These findings are further discussed below.

The behavioral results of the current study demonstrated a robust effect of WM load. We observed significantly lower accuracy rates, sensitivity scores, and higher WM capacity scores under high WM load relative to low WM load. Effects of emotion or an interaction between emotion and WM load did not emerge in any of the behavioral indices and were not modulated by anxiety either. A lack of anxiety effect on behavioral indices is not surprising as such indices are reflective of a summative indication of a multitude of WM processes ranging from early encoding to maintenance, and finally generation of a response. The influence of anxiety may emerge as processing costs or benefits at different stages of WM operations (i.e. impairments in maintenance; Qi, Ding, & Li, 2014b). Furthermore, according to prominent theories of anxiety, anxiety vulnerability should exert its effects mainly on processing efficiency, i.e., the manner in which cognitive resources are recruited towards a specified goal outcome, rather than the effectiveness of the performance outcome, i.e., accuracy rates (Eysenck & Calvo, 1992; Eysenck et al., 2007; Berggren & Derakshan, 2103). Similarly, there have been many studies observing effects of anxiety at the ERP level with no anxiety modulations emerging at the behavioral level (e.g., Ansari & Derakshan, 2011; Qi et al., 2014a; Qi et al., 2014b).

The ERP components of interest were measured at different time windows during the retention interval: N170 (for early processing) and CNV (for late processing). Since the early face-specific component of the N170 is mainly related to structural encoding of faces, the absence of valence-specific effects for the N170 is not surprising (Rossion & Jack, 2011; Vuilleumier & Pourtois, 2007). Previous research shows that the amplitude of the N170 increases as WM load (number of faces to be encoded) increases (Morgan, Klein, Boehm, Shapiro, & Linden, 2008; Langeslag, Morgan, Jackson, Linden, & Van Strien, 2009). While in our study, N170 activity was not modulated by WM load or emotion, its interaction with anxiety indicated that high levels of anxiety vulnerability were associated with greater N170 amplitudes under high relative to low WM load. Thus, our findings show that the main effect of WM load could depend on levels of anxiety vulnerability with high trait anxious individuals processing the faces to a greater extent under high WM load relative to low WM load. One possible explanation for that can be a hypervigilance account of anxiety (see Eysenck, 1992) which associates anxiety with increased monitoring of the environment for potential threat. Enhanced visual processing in relation to elevated anxiety is also shown by Berggren, Bloniievsky, and Derakshan (2015). In this study, participants had to detect an additional stimulus while performing a visual search task. Berggren and colleagues (2015) demonstrated that high anxious participants had greater sensitivity while detecting the additional stimulus suggesting increased monitoring and widened attention in relation to elevated anxiety. Similarly, other studies investigating the role of anxiety on processing task-irrelevant stimulus under high and low perceptual task demands showed that high anxiety was related to greater allocation of attention to additional/task-irrelevant stimulus as such high anxious participants processed the additional stimulus even under high perceptual load conditions (Moriya & Tanno, 2010; Sadeh & Bredemeier, 2011).

Our findings regarding the CNV were very interesting. While we did not observe a main effect of WM load or emotion, the interaction between load and emotion revealed that the CNV response was greater under high WM load compared with low WM for neutral faces, with the reverse found for the CNV response for fearful faces: lower CNV under high relative to low WM load. Previous literature has showed that the CNV amplitude is sensitive to the recruitment of cognitive resources in relation to task demands and cognitive effort, as well as motivational factors towards achieving task goals (McEvoy, Smith, & Gevins, 1998; Wild-Wall et al., 2006; Ansari & Derakshan, 2011; Judah et al., 2013; Schevernels, Krebs, Santens, Woldorff, & Boehler, 2014). Accordingly, increased CNV activity under high WM load as compared to low WM load may reflect increased levels of cognitive effort in response to the greater attentional demands required under high load. However, this effect was observed only when faces depicted neutral expressions as there was lower a CNV in response to fearful expressions under high relative to low WM load. Furthermore, this was even more evident for high anxious individuals. These results may indicate high anxious individuals have difficulties in exerting cognitive effort in response to task demand when they have invested processing resources in fearful faces.

Importantly, the N170/CNV relationship under high relative to low WM load was modulated by trait anxiety levels such that anxiety showed a moderating effect on the amplitude of the N170 and its potential in predicting the amplitude of the CNV when expressions were fearful. In this regard, higher levels of anxiety and higher levels of the N170 were associated with a lower CNV response. This finding suggests that when cognitive resources are taxed under high WM load, fearful faces are processed to a larger extent in anxious individuals. Enhanced processing of fearful distracting stimuli in the context of the current design can reflect an early attentional bias towards threat in anxiety (Bar-Haim et al., 2007). While speculative, the results of the current investigation are suggestive of a possible relationship between early distractibility by fear in anxiety that compromises the mechanisms behind recruitment of prefrontal control further. It should also be noted that our results with regard to N170/CNV relationship was only marginally significant which might be due to a small sample size. Hence, future studies are recommended with a larger sample size.

In summary, results of the current investigation suggest that anxiety is related to enhanced distractibility by fearful expressions at early stages of processing that can potentially impact the recruitment of cognitive effort at subsequent stages of processing that depend upon the effortful and efficient recruitment of responses towards task goals. Furthermore, these processes were negatively related to each other suggesting an interplay between early vs late information processing. This study is amongst the first to assess encoding of threat-related information in WM with respect to early and late stages of processing. Results of the current study are valuable to understand anxiety-related information-processing biases and impairments, which are hallmark of anxiety disorders (Eysenck, 1992). Future studies are recommended to focus on different ERP components in different time windows in order to gain greater understanding of this relationship.

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CHAPTER 3

THE EFFECTS OF STATE ANXIETY ON WORKING MEMORY IN RELATION TO EMOTION AND COGNITIVE LOAD[1]

ABSTRACT

Attentional bias to threat, a vulnerability factor to anxiety and negative affect, is usually associated with impaired attentional control and working memory (WM), especially in individuals with high trait anxiety; however, research concerning state anxiety effects is rather scarce (Bar-Haim et al., 2007). Hence, the current investigation focused on the effects of state anxiety on WM in the presence of threat-related stimuli under varying levels of cognitive load. For this purpose, we used an experimental paradigm which combines two tasks: 1-back task (to ensure encoding of fearful/neutral stimuli); and a number recognition task (to manipulate cognitive load). Prior to the start of the experiment, state anxiety was manipulated via threat of shock. Participants in the anxiety/experimental condition (N = 29) were told that they would receive electrical shock in the second part of the experiment while participants in the control condition (N = 29) were told that they would never receive any electrical shock. Results demonstrated that elevated state anxiety (self-reported anxiety scores after the manipulation as well as pre to post manipulation changes in these scores) was related to reduced interference by threat-related stimuli, under high load condition selectively. This effect was not observed under the low load condition. As such, these findings provide a better understanding of the modulatory effects of state anxiety on WM performance, which seem to depend on both the presence of threat-related information in the environment and cognitive load.

[1] Sari, B. A., Pourtois, G., Derakshan, N., & Koster, E.H. (2016). The effects of state anxiety on working memory in relation to emotion and cognitive load. *Unpublished manuscript.*

INTRODUCTION

Attentional bias, defined as the exaggerated tendency to attend to threatening stimuli in the environment (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van Ijzendoorn, 2007), is a characteristic feature of anxiety and anxiety disorders (MacLeod, Mathews, & Tata, 1986; Eysenck, 1992; Beck & Clark, 1997). There is a wealth of studies documenting the role of attentional bias on performance in relation to elevated trait anxiety (i.e., when it is conceived as a stable disposition or personality characteristic), yet evidence with regard to the possible influences of state anxiety is much less documented in the literature (Bar-Haim et al., 2007).

State anxiety is usually described as a transient emotional state of tension and apprehension, while trait anxiety is referred to as a personality disposition characterized by proneness to interpret situations as threatening, and the tendency to respond to such situations with elevated state anxiety (Spielberger, 1972; Elwood, Wolitzky-Taylor, & Olatunji, 2012). A substantial amount of studies focused on the role of trait-anxiety on cognitive performance have demonstrated that high trait anxiety is related to impaired attentional control and working memory (WM) in the presence of threat-related distractors (Bar-Haim et al., 2007) and also established a link between trait anxiety and general impairments in attentional control and WM (see Eysenck, Santos, Derakshan, & Calvo, 2007; Berggren & Derakshan, 2013 for reviews).

Many studies have investigated the nature and extent of the interaction effect between trait and state anxiety in the past. These investigations often pointed out that high trait anxiety in combination with high state anxiety was most strongly associated with increased attentional bias and greater interference by threat-related stimuli (MacLeod & Mathews, 1988; Richards, French, Johnson, Naparstek, & Williams, 1992; MacLeod & Rutherford, 1992; Egloff & Hock, 2001) as well as reduced WM capacity (Sorg & Whitney, 1992).

Relative to research on trait anxiety, studies examining effects of state anxiety (in isolation) on threat processing are the exception rather than the rule. Some of these investigations demonstrated that (similar to trait anxiety) elevated state anxiety also increased attention to threat-related stimuli (Fox, Russo, Bowles, & Dutton, 2001; Mathews & MacLeod, 1985; Mogg, Bradley, De Bono, & Painter, 1997; Bishop, Jenkins, & Lawrence, 2007). Furthermore, Lystad, Rokke and Stout (2009) showed that the presentation of a negative stimulus facilitated processing of subsequent (neutral) stimuli in relation to high state anxiety, suggesting anxiety-related performance benefits. Indeed, several investigations assessing the role of state anxiety on sustained attention and response inhibition have demonstrated that elevated state anxiety is related to better response inhibition (Robinson, Krimsky, Grillon, 2013; Grillon, Robinson, Mathur, & Ernst, 2015). These performance benefits can be explained in terms of heightened vigilance as a function of state anxiety (Eysenck, 1992). Heightened vigilance can lead to enhanced monitoring and increased attention which may facilitate in turn task performance. In line with this view, Pacheco-Unguetti, Acosta, Callejas and Lupianez (2010) demonstrated that high state anxiety was related to greater *orienting to sensory events* and *maintaining vigilant state* functions (Posner & Petersen, 1990).

In addition to studies focusing on attention, several studies also investigated the role of state anxiety on more complex cognitive processes, such as WM. WM is a cognitive system with limited capacity which is essential to perform complex tasks (Baddeley, 1992). Using an n-back task with spatial and verbal components, Shackman and colleagues showed that elevated state anxiety was specifically related to impaired spatial WM while such an effect was not observed for verbal WM (Shackman, Sarinopoulos, Maxwell, Pizzagalli, Lavric, & Davidson, 2006; also see Lavric, Rippon, & Grey, 2003). However, other studies investigating the relationship between state anxiety and WM demonstrated that state anxiety was also related to impairments in verbal WM, yet it might depend on the task load level (Vytal, Cornwell, Arkin, & Grillon, 2012; Vytal, Cornwell, Letkiewicz, Arkin, & Grillon, 2013). In these investigations, Vytal et al. (2012; 2013), observed impairments in verbal WM only under low cognitive load when the task was less demanding. However, these studies only used emotionally neutral tasks (n-back task with letters) to investigate the relationship between WM and state anxiety, leaving the influence of threat-related stimuli on this relationship unexplored. Therefore, the current investigation focused on the effect of state anxiety on WM considering cognitive load and (threat-related) stimulus content (emotionality). For this purpose, we used a WM task which allowed us to examine WM processing under varying levels of cognitive load in the presence of either neutral or threat-related stimuli. The experimental paradigm elected combined two interspersed tasks, namely a 1-back task (to ensure encoding of emotional information) and a number recognition task (for manipulation of cognitive load). The current paradigm provides a variant (with the addition of an emotional component) of the task previously used by de Fockert, Rees, Frith and Lavie (2001). Before the WM task, state anxiety was induced via threat of shock (Robinson, Vytal, Cornwell, & Grillon, 2013). Half of the participants were told that they would receive electrical shock during the second part of the experiment (anxiety condition) while the other half were told they would not receive any electrical shock (control condition).

Our study seeks to better understand the complex relationship between state-anxiety and WM, when considering emotion and cognitive load as possible modulatory factors. We formulated several predictions. First, we expected to observe a strong effect of cognitive load on task performance, with lower accuracy rates in the high as compared to the low cognitive load level, regardless of anxiety levels. Furthermore, we expected to observe that (state) anxiety would modulate the processing of emotional material selectively, given the close link between anxiety and the processing of threat-related information (Bar-Haim et al., 2007). This effect was expected to be further modulated by cognitive load since anxiety-related effects on performance can vary depending on task demands (Eysenck et al., 2007; Vytal et al., 2012; Berggren & Derakshan, 2013; Rossi & Pourtois, 2015). Considering previous mixed findings showing that state anxiety can be related to performance benefits in the presence of threat-related stimuli (i.e. Lystad et al., 2009) as well as impairments in WM (i.e. Vytal et al., 2012), we did not formulate, however, strong predictions with regard to the directions of emotion and load effects. Hence, exploratory analyses were conducted assessing the influence of anxiety on WM performance considering emotion and cognitive load.

METHOD

Participants

Fifty-eight participants (13 male) aged between 17- 47 (*M* = 24, *SD* = 6) were recruited from the campus at Ghent University. They were first randomly assigned to either 'anxiety' (*N* = 29) or 'control' (*N* = 29) condition. The data for 10 participants were removed from subsequent analyses due to an excessive error rate (>50%). The final sample included 25 participants in the 'anxiety' and 23 participants in the 'control' condition.

Materials and Procedure

Questionnaires. Self-report questionnaires of trait and state anxiety (State Trait Anxiety Inventory, STAI-SA, STAI-TA; Spielberger, Gorsuch, Lushene, & Vagg, 1983) were administered. STAI is a 40-item (20 items in state sub-scale and 20 items in trait sub-scale) self-report instrument with good psychometric properties (Spielberger & Reheiser, 2004). Respondents indicate the degree to which they experience each of the items on a four-point scale (1="almost never" to 4="almost always"). We also assessed mood ratings (happiness, sadness, calmness and anxiety) by means of 0-100 mm visual analogue scales (VAS; 0 = not at all, 100 = extremely).

Working Memory Task

Stimuli. Fearful and neutral images from the International Affective Picture Set (IAPS; Lang, Bradley, & Cuthbert, 1999) were used. For each category, 16 images were eventually chosen. The numbers of the IAPS pictures used were as follows: fearful: 1120, 1201, 1274, 3051, 3530, 6200, 6210, 6230, 6243, 6250, 6300, 6370, 6550, 6570, 6571, 9405; neutral: 7620, 7595, 7560, 7510, 7504, 7500, 7496, 7495, 7234, 7205, 7130, 7037, 7036, 5535, 2745.1,7700.

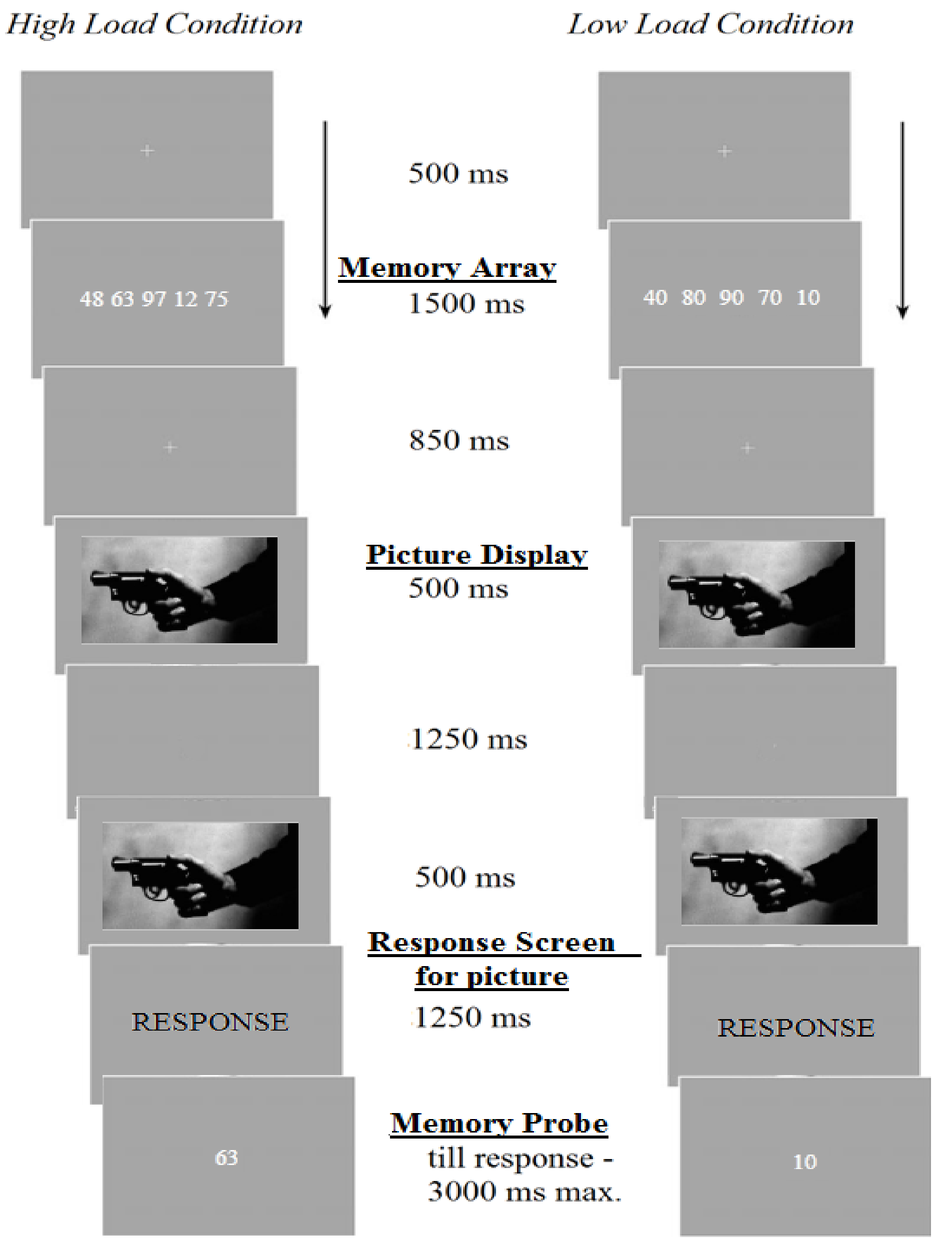
Experimental Paradigm. The WM task was based on the task devised previously by de Fockert et al. (2001). Participants were asked to perform two different tasks on each and every trial: a one back task and a number recognition task (see Figure 1).

The task started with the presentation of 5 numbers (each digit; 0.4^o x 0.6^o) for 1500 ms. Participants were asked to memorize them. Afterwards, two pictures (5^o x 6^o) appeared on the screen consecutively. Each picture was presented for 500 ms with a 1250-ms ISI. Participants were asked if these two pictures were the same or not (one-back "matching" task). They gave their answers only when they saw the "response" screen which remained for 1250 ms. Finally, a (single) number appeared on the screen and participants had to indicate (as accurately as possible) whether this number was one of the 5 numbers that they had seen at the beginning of the trial (number recognition task).

Within this task, two main factors were manipulated; the level of cognitive load (low vs. high) and the emotionality of the pictures (being neutral or threat-related). In the low cognitive load condition, the numbers were always ten-fold, two digit numbers (10, 20, …, 90). By comparison, in the high cognitive load condition, the number list included all possible two digit numbers (10, 11, 12,…., 99). Within a trial, the emotional content of the two pictures (either neutral or threat-related) did not differ. If two pictures presented were the same, the trial was termed a match one-back trial. If the number presented at the end of the trial matched one of the (five) numbers presented at the beginning, it was termed a match number recognition trial.

Before starting the task, there was a practice session with 15 neutral trials. The pictures used for the practice were different than the ones used in the main task. There were two main blocks that differed with regard to cognitive load: a low cognitive load and a high cognitive load block. The starting load level was counterbalanced across participants. In each block (n = 48 trials), neutral and fearful pictures were presented equally often in random order. Emotionality and match/no-match status varied across trials, in a random fashion. The task lasted approximately 20 minutes.

Figure 1. Decomposition of a trial. The left panel refers to the high cognitive load condition (any random 2-digit 5 numbers) while the right panel refers to the low cognitive load condition (5 numbers of 10-folds).



Procedure. Participants read and signed the informed consent form. They then completed the state and trait anxiety questionnaires and provided mood ratings using the VAS (time point 1). They were told that the study would consist of two parts: a cognitive part and a pain perception part. The pain perception part was announced to induce state anxiety. Participants were also told that they would be asked to rate their mood at various intervals during the experiment. Half of the participants were told that they would receive an electric shock (anxiety condition) during the pain perception part. The electric shock equipment was visible to participants. The electric shock machine was turned on, cables were attached to it, and the necessary arrangements were made to operate the machine. However, electric shocks were not delivered at any point during the experiment. Other participants were told that they would not receive any electrical shock (control condition). After the participants were informed about which condition they were assigned to, they were asked to fill in the state anxiety questionnaire and provided VAS mood ratings again (time point 2). They then completed the WM task which was introduced as the 'cognitive part' of the study. When the task was finished, they were asked to fill in the state anxiety questionnaire and provided VAS mood ratings for the last time (time point 3). In the end, they were debriefed and interviewed to assess whether the pain perception scenario was believable. At the end of the experiment, participants were paid 5 euro for their contribution.

Data Analytic Approach. The main dependent variable of the WM task was accuracy rate in the number recognition task[2]. In order to investigate the effects of cognitive load and emotion on task performance, we first conducted a 2 (high vs low cognitive load) x 2 (neutral vs fearful) ANOVA. Next, condition (anxiety vs control) was included as a between-subject factor in the analysis to investigate whether the relationship between cognitive load and emotion differed as a function of condition.

Provided that there were considerable individual differences in response to the state anxiety manipulation (cf. Grol, Koster, Bruyneel, & De Raedt, 2014; Sari, Koster, & Derakshan, 2016), further analyses focused on WM task performance also considered the level of anxiety as covariate regardless of the condition participants were initially assigned to. This approach allowed us to take into account inter-individual differences in state anxiety and increase statistical power by conserving greater degrees of freedom. Self-report anxiety scores assessed via STAI-SA and VAS at post-manipulation (time 2) were included in the analyses as they are the most reflective of the level of state anxiety just before the WM task. The other VAS ratings on sadness, calmness and happiness were mainly included to reduce the focus on anxiety and assess the specificity of the state anxiety induction. In addition, STAI-SA scores and VAS anxiety ratings at post-manipulation, pre to post manipulation change in anxiety levels were also considered (cf., Grol et al., 2014), because the contrast with former emotional state might have an influence on latter emotional experience (affective contrast theory, Bacon, Rood, & Washburn, 1914; Manstead, Wagner, & MacDonald, 1983). Change scores were calculated by subtracting level of anxiety at pre-manipulation from post-manipulation: STAI-SA/VAS anxiety at post-manipulation – STAI-SA/VAS anxiety at pre-manipulation. Higher scores in these indexes indicated greater increase in anxiety following the state anxiety induction.

In order to investigate how the actual level of state anxiety modulated the relationship between cognitive load and emotion, 2 (high vs low cognitive load) x 2 (neutral vs fearful) ANCOVAs were conducted with post-manipulation anxiety levels as covariate (both for STAI-SA scores and VAS anxiety ratings separately). Similar analyses were repeated also using pre-post manipulation change scores in anxiety levels as covariate. Significant three-way interactions were followed-up by correlational analyses. To this end, we first calculated interference scores by subtracting accuracy scores in fearful trials from the accuracy scores in neutral trials (Accuracy Neutral – Accuracy Fear) for each of the cognitive load conditions separately. Greater scores in these indexes indicated greater interference by fearful stimuli. Correlational analyses were conducted for low and high cognitive load conditions separately; and in order to investigate whether these two dependent correlation coefficients were significantly different from each other in strength Steiger test (Steiger, 1980) was performed.

RESULTS

Group Characteristics

Trait anxiety scores did not significantly differ between the control (M = 37.7, SD = 9.34) and anxiety (M = 38.90, SD = 10.48) conditions, t < 1, *NS*. The two groups also did not differ from each other in terms of age (Control condition, M = 24, SD = 5;

Anxiety condition, *M* = 24, *SD* = 7), $t < 1$, *NS;* and gender; $X^2(1, N = 48) = .25$, $p = .62$. All participants reported that the pain perception scenario was believable.

Mood induction Check

Conditions did not significantly differ from each other in mood ratings and STAI-SA scores at the beginning of the experiment (time point 1; all *t*s < 1.3, *NS*). After the mood manipulation (time point 2), participants in the anxiety condition were significantly more anxious (VAS anxiety ratings, $t(46) = 2.15$, $p < .05$; STAI-SA, $t(46) = 2.66$, $p = .01$) than in the control condition. Importantly, the two conditions did not differ on any of the other ratings for sadness, happiness and calmness after manipulation (all *ts* < 1.2, *NS*). At the end of the experiment, the two groups did not differ from each other in any of the mood ratings or STAI-SA scores (all *ts* < 1.6, *NS*). Mean scores are presented in table 1.

Table 1. Mean VAS ratings and STAI-SA scores at pre-manipulation, post-manipulation and after the task for anxiety and control conditions. SDs are reported in parenthesis.

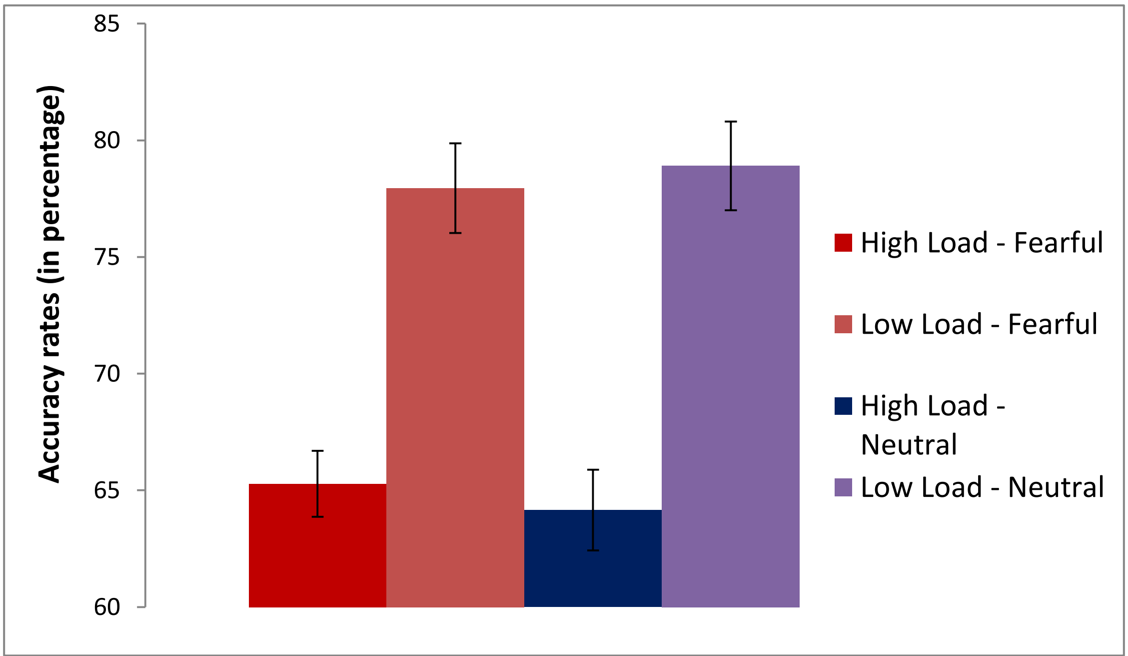
	Pre-manipulation		Post-manipulation		After the Task	
	Anxiety condition	Control condition	Anxiety condition	Control condition	Anxiety condition	Control condition
STAI-SA	38 (13)	33 (11)	42 (13) *	32 (11)	40 (12)	36 (11)
Anxiety Ratings	27 (33)	18 (22)	29 (29) *	14 (17)	26 (31)	15 (18)
Happiness Ratings	69 (23)	69 (21)	67 (23)	73 (21)	63 (25)	71 (20)
Calmness Ratings	70 (24)	72 (26)	65 (28)	74 (25)	67 (28)	68 (21)
Sadness Ratings	21 (29)	19 (26)	24 (28)	20 (25)	21 (26)	18 (23)

* Indicates a significant difference between the anxiety and control conditions, $p < .05$

Working Memory Task

The 2 X 2 ANOVA with cognitive load (low vs high cognitive load) x emotion (neutral vs fearful) as within-subject factors showed a significant main effect of cognitive load, $F(1, 47) = 71.18$, $p < .001$, indicating, as expected, higher accuracy rates in the low (M = 78%, SD = 11) as compared to the high cognitive load condition (M = 65%, SD = 9). There was no significant main effect of emotion or two-way interaction effect (all *Fs* < 1, *NS;* See Figure 2 for descriptive statistics). When the condition was included as a between-subject factor, there was a significant main effect of load, $F(1, 46) = 71.05$, $p < .001$. However, main effect of emotion ($F < 1$, *NS*) and interaction effects were not significant (for emotion x condition interaction, $F(1, 46) = 2.67$, $p = .11$; for all other interaction effects, *F*s < 1.6, *NS*).

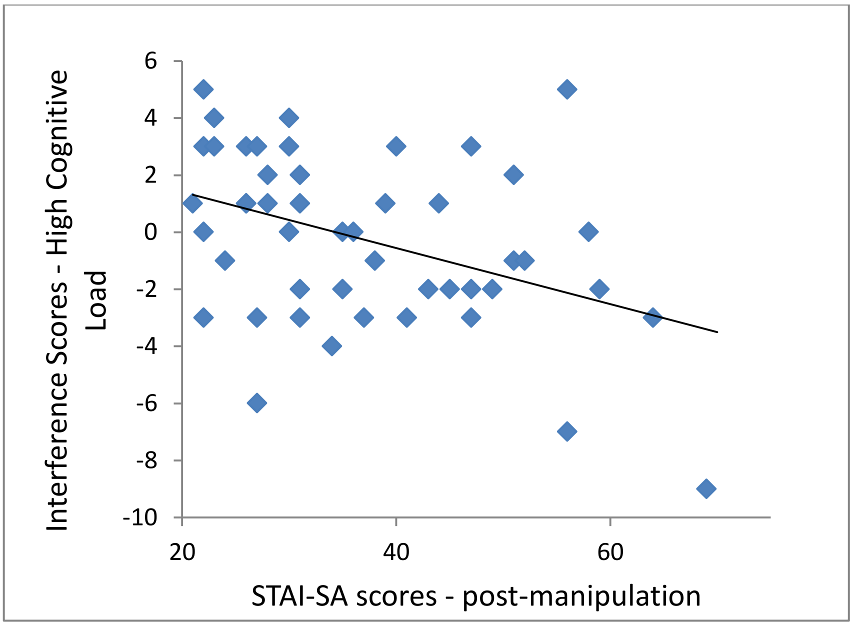
Figure 2. Mean accuracy rates in each condition for number recognition (WM) task (bars indicate standard errors).



Including STAI-SA post-manipulation scores as covariate, the ANCOVA revealed significant main effects of cognitive load, $F(1, 46) = 10.23$, $p < .01$; and emotion, $F(1, 46) = 4.73$, $p < .05$ (Fearful trials, M = 71.62%, SD = 9.19; Neutral trials M = 71.53%, SD = 10.28). There was also a significant emotion x STAI-SA interaction, *F*(1,

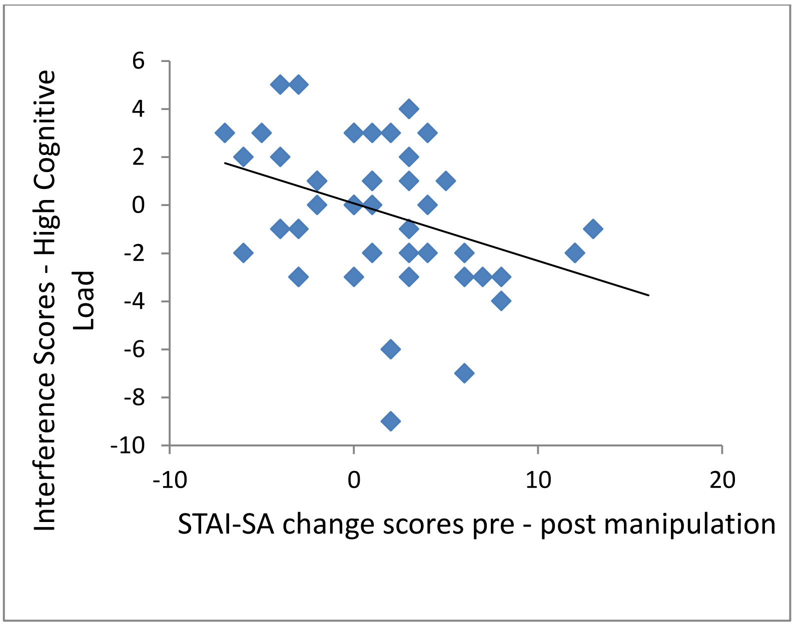
46) = 5.38, $p < .05$. This two-way interaction was subsumed under the (marginally) significant cognitive load x emotion x STAI-SA interaction ($F(1, 46) = 3.45$, $p = .07$). All other interaction effects were non-significant, all *F*s < 2.4, *NS*. Correlational analyses showed that there was a significant negative relationship between interference scores and STAI-SA in high cognitive load condition, $r(48) = -.41$, $p < .01$ (Figure 3). This correlation was still significant after controlling for STAI-TA scores by partial correlation, $r(48) = -.36$, $p = .01$. Such correlation was not found in low cognitive load condition, $r(48) = -.03$, $p = .83$. Furthermore, these two correlation coefficients were marginally different from each other, Steiger's $z = 1.90$, $p = .06$. The significant negative correlation between STAI-SA and interference scores indicated that higher level of state anxiety was related to lower interference by threat in the high cognitive load condition.

Figure 3. Correlation between interference scores in high cognitive load condition and STAI-SA scores at post-manipulation.



When pre-post manipulation changes in STAI-SA scores were used as a covariate, the ANCOVA showed a significant main effect of cognitive load, $F(1, 46) = 60.88$, $p < .001$; while the main effect of emotion did not approach significance, $F < 1$, *NS.* Furthermore, there was a significant cognitive load x emotion x STAI-SA change score interaction, $F(1, 46) = 4.73$, $p < .05$. Other interaction effects were non-significant (all *F*s < 2.5, *NS*). This significant three-way interaction was followed-up by correlational analyses. There was a significant negative relationship between interference scores and STAI-SA change scores in the high cognitive load condition, $r(48) = -.37$, $p < .01$ (Figure 4). This correlation was still significant after controlling for STAI-TA scores by partial correlation, $r(48) = -.40$, $p < .01$. However, such correlation was not observed in low cognitive load condition, $r(48) = .07$, $p = .64$. Furthermore, these two correlation coefficients were also significantly different form each other, Steiger's $z = 2.18$, $p < .05$. The significant negative correlation between STAI-SA change scores and interference scores indicated that elevated anxiety pre to post-manipulation was associated with lower interference by threat in the high cognitive load condition.

Figure 4. Correlation between interference scores in high cognitive load condition and change in STAI-SA scores pre to post manipulation.



Using VAS anxiety post-manipulation ratings as a covariate, the ANCOVA revealed significant main effects of cognitive load, $F(1, 46) = 52.45$, $p < .001$; and emotion, $F(1, 46) = 4.24$, $p < .05$. There was also a significant interaction between emotion and VAS anxiety, $F(1, 46) = 10.41$, $p < .01$. Other interaction effects were not significant, all *F*s < 1.7, *NS*. The two-way interaction was followed-up by correlational analyses between VAS anxiety ratings and accuracy rates in fearful and neutral conditions separately averaged across cognitive load conditions. These analyses revealed a significant negative relationship between VAS anxiety ratings and accuracy rates in the neutral condition, $r(48) = -.33$, $p < .05$; but not in the fearful condition, $r(48) = .03$, $p = .85$.

Lastly, we included pre-post manipulation change in VAS anxiety ratings as covariate. Results revealed a significant main effect of cognitive load only, $F(1, 46) = 70.55$, $p < .001$ (For the main effect of emotion, $F < 1$, *NS*; for all other interaction effects, *F*s < 2.2, *NS*).

DISCUSSION

The current study investigated the relationship between state anxiety and WM in the presence of threat-related stimuli considering cognitive load. We expected to observe impairments in WM performance under high compared to low cognitive load regardless of anxiety. Emotion effect (interference by threat-related stimuli) was expected to emerge in relation to state-anxiety depending on changes in task demands (high vs low cognitive load). As expected, our results showed that participants had lower accuracy rates under high compared to low cognitive load condition. A main effect of emotion was observed only in relation to anxiety. More specifically, results demonstrated that elevated state-anxiety was related to reduced interference by threat under high cognitive load condition; and this effect was most pronounced in relation to pre- to post-manipulation increase in the level of state anxiety, as assessed via STAI-SA. Similar results were not observed in relation to VAS anxiety ratings. Furthermore, cognitive load and emotion effects did not vary as a function of condition (anxiety vs control). The possible implications of these findings are discussed below.

Our results are in line with the previous studies investigating the role of state-anxiety in attention where elevated state-anxiety facilitated subsequent cognitive processes after the presentation of threat-related stimuli (Lystad et al., 2013; Birk, Shin, Dennis, & Urry, 2011). State anxiety-related benefits on performance could be due to increased vigilance which can lead to increased monitoring and broader attention (Eysenck, 1992; Robinson et al., 2013; Berggren, Blonievsky, & Derakshan, 2015; Grillon et al., 2015; but also see Birk et al., 2011). Furthermore, current findings are also in accordance with mood congruency accounts (Bower, 1981); as anxious mood can apparently enhance performance in the presence of threat-related stimuli (Lystad et al., 2013).

Findings of the current study are different from previous studies where adverse effects of state-anxiety were observed on WM when using emotionally neutral WM tasks (Lavric et al., 2003; Shackman et al., 2006; Vytal et al., 2012; 2013). This discrepancy between previous findings and our results suggests that the effects of state-anxiety on WM can differ based on the mere presence of threat-related (and presumably mood-congruent) stimuli in the environment. Furthermore, Vytal et al. (2012; 2013) observed anxiety-related effects on WM under low cognitive load; whereas, in the current study, we mainly observed anxiety-related effects under high cognitive load. Vytal et al. (2012; also see King & Schaefer, 2011) explained the lack of anxiety-related effects under high cognitive load in terms of decrements in anxious mood in this condition. However, it is unlikely that this has been the case in the current study since the possibility of decrement in anxious mood under high cognitive load does not explain why performance benefits were observed in this condition in relation to elevated anxiety; and also why no effects of anxiety (either benefit or cost) were observed under low cognitive load. Lack of anxiety-related effects under low cognitive load in our study is also in accordance with studies in trait anxiety proposing that anxiety-related effects on WM become more evident when the task is cognitively demanding (i.e. Qi et al., 2014; also see Berggren & Derakshan, 2013 for a review).

The results of the current study suggest beneficial effects of state anxiety on WM in the presence of threat-related stimuli; and this effect remained significant even after controlling for trait anxiety. However, it should be noted that participants were not pre-selected based on trait anxiety; and the average level of trait anxiety was only moderate (STAI-TA scores in the current investigation, $M = 38$, $SD = 9.86$; average normative STAI-TA scores of Dutch student population, $M = 35$, $SD = 8.40$; Van der Ploeg, 1982). Hence, based on our findings, it is difficult to draw any firm conclusions with regard to the role of trait anxiety (or the tack thereof), which is closely associated with clinical anxiety (Eysenck, 1992). Recently, Vytal, Arkin, Overstreet, Lieberman and Grillon (2016) investigated the role of state anxiety on WM in a sample of GAD patients and healthy controls; and they observed differential effects of state anxiety on performance in these two groups. While GAD patients had impaired WM regardless of the cognitive load (level) in the anxiety condition (threat of shock), healthy controls in the anxiety condition had impaired WM only under low cognitive load. Furthermore, Vytal et al. (2016) observed that (similar to our results) healthy controls had improved WM under high cognitive load in the anxiety condition; yet this gain has been associated with reduced anxious mood under high cognitive load.

It should also be noted that, in the current study, we did not observe any significant differences on WM performance in relation to cognitive load and emotion as a function of condition (anxiety vs control). However, load and emotion effects were modulated via individual differences in state anxiety levels regardless of the condition. This finding is inline with previous studies where there were considerable individual differences in response to mood manipulation; and the effect of mood manipulation on performance was observed when these differences were taken into account (Grol et al., 2014; Sari et al., 2016). Furthermore, the relationship between cognitive load and emotion was specifically modulated by STAI-SA scores, yet similar results could not be found using VAS anxiety ratings. These two measures are typically highly correlated with one another (i.e. correlation coefficient between VAS ratings and STAI-SA scores after the manipulation; $r(48) = .80$, $p < .001$); and both of them are considered valid instruments to assess momentary fluctuations in levels of state anxiety, STAI-SA (Rossi & Pourtois, 2012). Presumably, in the current investigation, the use of a multidimensional scale targeting different aspects of anxiety (i.e. *apprehension, tension, nervousness, worry, arousal*; Spielberger & Reheiser, 2004; 2009) might have been more sensitive to capture fine-grained qualitative changes in the actual mood state of the participant as a result of the mood induction procedure. Because the STAI-SA might have provided a compound measure of these different aspects/dimensions, it could potentially explain why it did account for a differential performance level across the different conditions in our study, unlike the simpler and undifferentiated VASes used here.

In the current study, we manipulated state anxiety using (the prospect of) threat of shock which targets mainly anxious arousal component of anxiety (Phelps, O'Connor, Gatenby, Gore, Grillon, & Davis, 2001; Robinson, Vytal, Cornwell, & Grillon, 2013). Hence, it is difficult to ascertain whether the effects we observed were specific to state anxiety (i.e., anticipatory anxiety) or heightened arousal levels. Besides arousal or (hyper)vigilance, anxiety usually has a strong cognitive component in the form of worry (anxious apprehension; Liebert & Morris, 1967; Heller & Nitschke, 1998; Mathews, 1990); and the worry component of anxiety is also closely related to impairments in WM and attentional bias towards threat (Hirsch & Mathews, 2012). Hence, future studies are desired to focus on the distinction between anxious arousal and worry; and also investigate WM performance (benefit or cost) in relation to induced worry in order to better elucidate under which circumstances state anxiety dynamically influences WM.

The current study investigated the role of state anxiety on WM in the presence of threat considering low/high task demands. Results suggest anxiety-related performance benefits in WM in the presence of threat-related stimuli, under high cognitive demands selectively. As such, this study allows to gain a better understanding of the nature and extent of modulatory effects exerted by state-anxiety on WM in (unselected) healthy adult participants. Future studies are needed to assess whether worry for example, as opposed to state anxiety as such or broadly defined, can eventually underlie this gain in WM in the presence of threat-related information in the environment when negative affect is transiently experienced. This line of research might ultimately be valuable to explore cognitive vulnerability factors in anxiety disorders.

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CHAPTER 4

THE EFFECTS OF ACTIVE WORRYING ON WORKING MEMORY CAPACITY [1]

ABSTRACT

According to the Attentional Control Theory of Anxiety (Eysenck, Derakshan, Santos & Calvo, 2007), worry, a crucial component of anxiety, impairs task performance outcome(s) through its direct effect on working memory capacity (WMC), by using up the limited resources available for performance thus reducing attentional control. We tested this hypothesis in the current study by examining the causal influence of active worrying on WMC in a sample of undergraduate university students assigned either to a worry condition (*N* = 32) in which state worry was induced or to a non-worry control condition (*N* = 32). Participants performed a change detection task before and after the worry/control manipulation. Mediation analyses showed that the level of self-reported worry mediated the effects of condition on change in WMC as demonstrated by the significant indirect effect of worry and the resulting non-significant direct effect of condition on change in WMC. Similar results were obtained when using state anxiety measures as mediating factors. Results of the current study are amongst the first to demonstrate that worry impairs WMC and as such have important implications for understanding the impact of worry in educational as well as clinical outcomes.

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INTRODUCTION

Worry has been described as a state of experiencing uncontrollable, apprehensive, and intrusive negative thoughts about the future (Borkovec, Robinson, Pruzinsky, & DePree, 1983). It is considered as a main cognitive characteristic of anxiety (Eysenck, 1982; Mathews, 1990), believed to hijack important attentional resources from a limited working memory capacity (WMC) system, leaving fewer resources available for task demands, thus reducing attentional control (e.g., Derakshan & Eysenck, 2009; Berggren & Derakshan, 2013; Hirsch & Mathews, 2012). According to the attentional control theory of anxiety (ACT; Eysenck, Derakshan, Santos, & Calvo, 2007), worry is a key mechanism explaining why efficient processing of the main executive functions of working memory are hampered in anxiety, leading to impaired or inefficient task performance.

While worry provides a mechanism by which the effects of anxiety on cognitive performance outcomes can be explained, there have been relatively few studies examining the possible causal influence of worry on cognitive performance. Hayes, Hirsch, and Mathews (2008) assessed the effects of worrying on performance using a random key-pressing task measuring attentional control. During this task, participants were asked to press any one of 15 buttons available upon hearing a beep. Randomness of button press was interpreted as a measure of attentional control since producing a more novel and random sequence requires a greater level of attention as compared to following a regular and practiced sequence. In that study, participants were assigned to a 'worry' condition where they were instructed to think of a personally relevant worrying concern and a 'control' condition where they were asked to think of a personally relevant positive future event while completing this task. Hayes et al. (2008) found that high trait worry was associated with fewer random button presses. Furthermore, high trait worriers produced less random sequences during the worry condition as compared to the control condition, which was not the case for the low worriers. This latter result was consistent with the prediction that state worry reduces processing efficiency, especially in individuals with trait characteristics compatible with this thinking style (see Eysenck et al., 2007). This finding was replicated in a sample of generalized anxiety disorder (GAD) patients (see Stefanopoulou, Hirsch, Hayes, Adlam, & Coker, 2014) who conducted the same task with the addition of completing an n-back working memory task first. In this study, working memory performance was also shown to be affected with GAD participants performing worse on the n-back task than control subjects.

More recently, two studies have looked at how trait vulnerability to worry modulates cognitive as well as neural processes related to attentional control. Stout, Shackman, Johnson and Larson (2015) using an emotional working memory (WM) task in healthy participants assessed the role of worry and anxiety in relation to working memory on filtering efficiency using an emotional face change detection task with faces depicting threatening and neutral expressions. In this task, participants were required to focus on the target faces and indicate if they had changed in a subsequent recall phase while ignoring the distracter faces. Results of this study demonstrated an increased filtering cost both for neutral and threat distracters in high trait anxious individuals. Furthermore, trait worry also increased filtering costs but for the threat related distractors only. In another study, using a modified version of the flanker task under low and high working memory load, where angry and neutral facial expressions of emotions served as distractors, Owens, Derakshan and Richards (2015) found that trait vulnerability to worry was associated with a greater recruitment of the N2 ERP component upon the inhibition of distractors with this neurophysiological effect being greater under high working memory load, providing support for the notion that trait worry reduces attentional control especially under conditions where attentional resources compete to meet task demands.

Extending recent demonstrations that trait vulnerability to worry reduces processing efficiency, the current study sought to establish that this effect can be explained through the effect of worry on WMC. Recent theoretical accounts (see Shipstead, Lindsey, Marshall, & Engle, 2014) have argued that WMC, i.e., the *efficacy* by which goal relevant information is attended, stored, and maintained while task irrelevant information is suppressed, is strongly related to attentional control. This suggests that in line with former predictions of ACT, active worrying should reduce WMC. To our knowledge, no study has directly examined the impact of active worrying on WMC in an unselected population. However, this research question is key in gaining a better understanding of how anxiety related impairments on cognitive performance in situations such as examinations for example, where the efficient regulation of attentional control is needed under competing task demands, could emerge. We assessed WMC using a modified visual change detection task (CDT) with (neutral) shapes (Owens, Koster & Derakshan, 2013) that was based on (Vogel, McCollough, & Machizawa, 2005). During this task, participants were instructed to remember the orientation of shapes and monitor change occurring between the sample display and the test display. In order to observe the influence of active worrying, we used a worry manipulation similar to Hayes et al. (2008). In a between subjects design, participants were asked to focus on either a worrisome concern (worry condition) or positive future event (control condition). They performed the CDT before and after the manipulation. This enabled us to test how active worrying causally influenced WMC. During the experiment, mood ratings in response to worry were also obtained. We predicted that increased worrying would be related to impaired WMC with reductions or limited improvements in WMC post vs. pre manipulation for the worry as compared to control condition.

METHOD

Participants

Sixty-four participants (27 male, 37 female) aged between 18-53 (M = 27, SD = 8) were recruited via advertisements from the campus of Birkbeck University of London (N = 39) and Ghent University (N = 25). They were compensated 5 GBP/5 Euro or given course credit for their contribution. The first participant was randomly assigned to either the ‘Worry’ (N = 32) or a ‘Control’ (N = 32) condition and subsequent participants were assigned to the different conditions alternately. Data from 10 participants were excluded either due to difficulties during the manipulation (i.e., they could not think of a personally relevant worrisome future event, N = 3), poor accuracy on the change detection task (less than 50% accuracy, N = 4), high response bias (false alarms more than 2.5 SD of the mean, N = 3), leaving a final sample of 54 individuals (26 in the ‘Worry’ and 28 in the ‘Control’ condition).

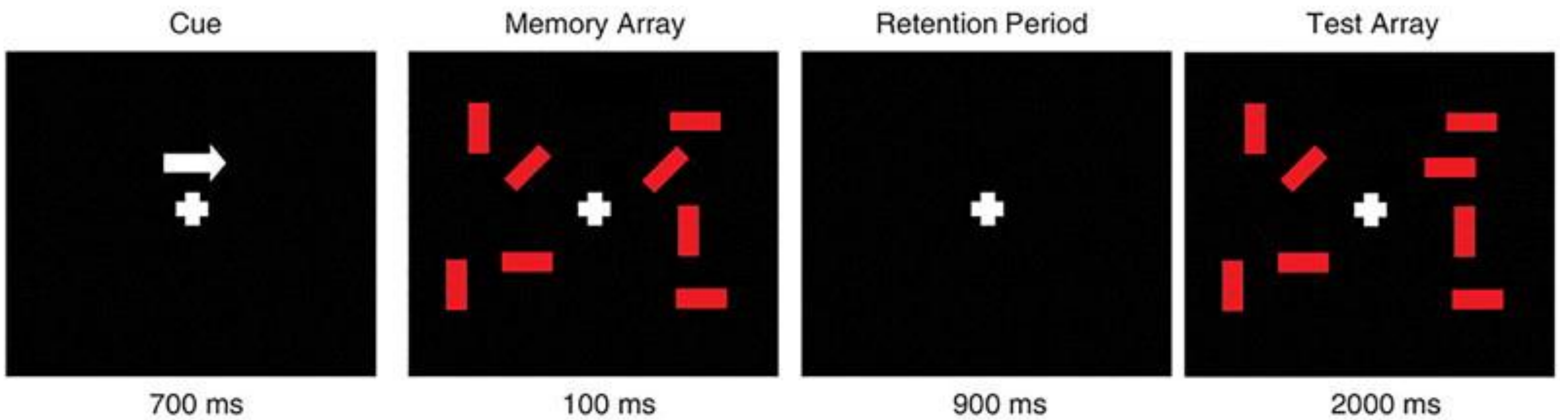
Materials and Procedure

Questionnaires. Participants completed the trait and state anxiety scales of the STAI (State Trait Anxiety Inventory; STAI; Spielberger, Gorsuch, Lushene, Vagg & Jacobs, 1983), the trait worry (Penn State Worry Questionnaire; PSWQ; Meyer, Miller, Metzger, & Borkovec, 1990) and the trait rumination scales (Ruminative Responses Scale, RRS; Nolen-Hoeksema & Morrow, 1991). During the experiment state worry and state anxiety were also assessed via 0 – 100 mm visual analogue scales (VAS; 0 = not at all, 100 = extremely).

Change Detection Task. A schematic overview of the trial sequence is presented in Figure 1. Each trial started with a fixation cross with an arrow above pointing either to the right or left (700 ms). This arrow served as cue and participants were informed to attend to the side of the screen indicated by this symbolic cue. Afterwards, either 2 or 4 rectangles appeared at the right and left side of the screen for 100 ms (3° away from the fixation cross, within a region of 4° x 7.2°; memory array). Participants were asked to memorize the orientation of the red rectangles on the attended side. After a retention interval of 900 ms, the rectangles reappeared at the right and left side of screen (test array). Participants were instructed to indicate whether the orientation of one of the (four or two) red rectangles they had memorized had changed or not within a two second interval, as accurately as possible.

The task included two item, four item, and distractor conditions. In the two item and four item conditions, all rectangles were red in color while the distractor condition included two blue rectangles as distractors in addition to the two red rectangles. In each condition, the rectangles appeared on random positions with a minimum of 2° distance from each other. There were 4 possible orientations for the rectangles: vertical, horizontal, 45° left and 45° right tilted. All possible conditions were randomly distributed within the task. There were 4 possible orientations for the rectangles: vertical, horizontal, 45° left and 45° right tilted. Fitting these criteria, we had 98 stimuli set for the four item, 105 stimuli set for the two-item and 101 stimuli set for distractor condition. The same stimuli set was not presented more than once during the task. All possible conditions were randomly distributed within the task.

Figure 1. Example of a 4-item condition in a change trial. Participants are instructed to remember the orientations of the rectangles, and respond during the test array to indicate whether a change occurred or not.



The task included four experimental blocks including 48 trials each (in half of the trials orientation of a rectangle has changed and in the other half it remained the same). Participants practiced the task until they reached an accuracy level of > 50% before starting the main experimental trials.

Procedure. Participants first read and signed the consent form. Then, they completed STAI-TA, PSWQ and RRS. Next, they performed the CDT, after which they provided mood ratings using VAS on the extent to which they felt worried, relaxed, happy and anxious (pre-manipulation). Afterwards, participants were assigned either to worry or control condition where they were asked to think of a personally relevant future event (in line with Stefanopoulou et al., 2014). In the worry condition participants focused on a personal concern or a worrisome event, whereas the control condition participants focused on a positive event. Since worry is strongly related to low self-esteem and beliefs about personal inadequacies (Davey & Levy, 1998), finding a personally relevant future scenario was strongly emphasized. Next, participants were shortly interviewed by the experimenter about these events for approximately 2 minutes. They were asked to discuss the positive (control condition) or negative (worry condition) aspects of the events they were focusing on. Once the interview was terminated, participants were told to actively keep thinking about the future events they just described until the end of the experiment. Then, mood ratings were taken for the second time (post-manipulation) alongside a question about the personal relevance of the event they had described. In addition to the mood ratings, participants also completed STAI-SA. Finally, they performed the CDT for the second time after which mood ratings were assessed for the final time (after the task). In the end, participants were asked to rate the frequency by which they had thought about the personal topic they had described earlier.

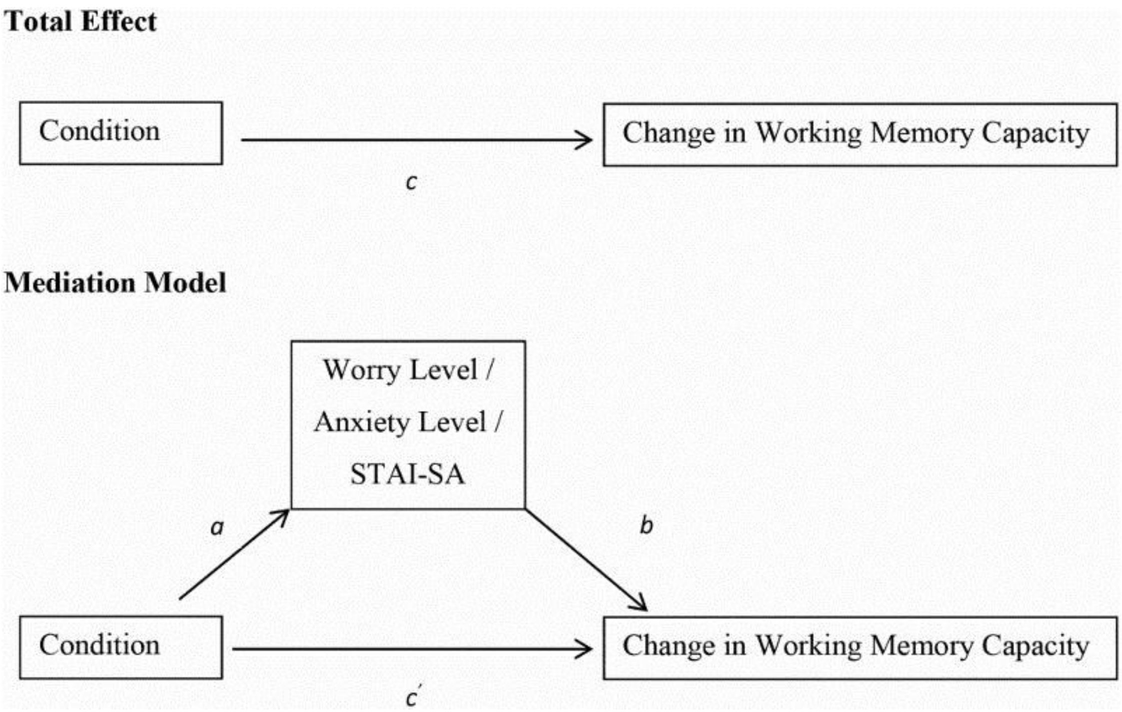
Data Analytic Approach. In order to assess performance on the CDT, we calculated WMC scores via the widely used formula (Pashler, 1988): $K = S \times (H - F)/(1-F)$ where K (WMC) is calculated as a function of S: the set size of the array, H: the observed hit rate and F: proportion of false alarms. In keeping with Lee, Cowan, Vogel, Valle-Inclan and Hackley (2010) and Owens et al. (2013), we calculated WMC for the four-item condition, eliminating possible ceiling or floor effects which can occur from two-item condition or distracter condition. In order to assess the level of worry during the task performance, we averaged the VAS scores for the worry ratings obtained after the manipulation (before starting CDT for the second time) and at the end of the task to produce an average score of worry (worry level). Since worry is defined as a more verbal and cognitive form of state anxiety (Mathews, 1990; Eysenck et al., 2007), we also calculated the same index for the VAS anxiety ratings (VAS anxiety level). In addition, STAI-SA scores were also included in our analysis. Strong correlations were observed amongst levels of worry, STAI-SA and VAS measures of anxiety (worry level and VAS anxiety level, $r(54) = .83$, $p < .001$; worry level and STAI-SA, $r(54) = .73$, $p < .001$; VAS anxiety level and STAI-SA, $r(54) = .62$, $p < .001$). Other VAS ratings on relaxed mood and happiness were obtained to reduce the sole focus on anxiety which could enhance anxious mood. Since the focus of the study was change in WMC as a function of the worry manipulation, we calculated change scores in WMC by subtracting the scores at pre-manipulation from the scores at post-manipulation. Larger change in WMC scores indicated improved performance at post-manipulation compared to pre-manipulation. Due to the variability in responding to mood manipulation (*cf*. Grol, Koster, Bruyneel & De Raedt, 2014) further analyses focused on the relationship between condition and WMC considering the level of worry or anxiety.

To test the main hypothesis, mediation analysis with condition as the independent variable, worry level as the mediating (intervening) factor, and change in WMC as dependent variable was conducted. Figure 2 depicts the tested model. In order to test the conditions of the mediation model (Mathieu & Taylor, 2006), significance of the indirect effect (path *ab*), the total effect (effect of condition on change in WMC scores without taking worry level into account (path *c*); and the direct effect (i.e., effect of condition on WMC scores after considering worry level (path *c'*) were investigated.

Significance of the indirect effect was tested using a bootstrapping approach (Preacher & Hayes, 2008) via random resampling (Hayes, 2013). We estimated 50,000 bias-corrected bootstrap 95% confidence intervals, excluding 0 for the indirect effect to be significant. These settings were chosen to increases the stability of the results.[2]

Significance of total effect (path c) and direct effect (path c') were tested and reported via regression coefficients. Similar mediation analyses were repeated with STAI-SA and VAS anxiety level as intervening variables, separately. All mediation models were controlled for heteroscedasticity. Analyses were conducted using IBM SPSS 19 and the macro PROCESS 2.13.2 (Hayes, 2013).

Figure 2. Theoretical diagram for indirect, total, and direct effects of condition on change in working memory capacity with either level of worry, anxiety or STAI-SA as an intervening variable.



[2] Although bootstrapping is a recommended method that is also robust in smaller sample sizes, in our study the upper-lower bounds of the confidence intervals varied slightly upon repetition of the analyses. Increasing the number of bootstrap samples is one of the ways to overcome this problem (Hayes, 2013). Hence, we used 50,000 bias-corrected bootstrap while 5000 or 10,000 are usually acceptable numbers.

RESULTS

Condition Description

Participants in the worry and control condition did not differ from each other on STAI-TA, PSWQ or RRS (all *t*s < 1, *NS*). There were no group differences in age (*t* < 1, *NS*) or gender distribution (c^2 (1, *N* = 54) = .32, *p* = .57).

Mood induction Check

Mood ratings at the beginning of the experiment (pre-manipulation) were compatible across conditions, all *t*s < 1.2, *NS.* As expected, participants in the worry condition were more worried, less relaxed, more anxious, and less happy than in the control condition (all *t*s > 4.5, all *p*s <.001) after the manipulation (post manipulation; see table 1 for descriptive statistics), although there was substantial individual variability within conditions. Furthermore, the worry condition had higher STAI-SA scores (*M* = 48, *SD* = 9) relative to the control condition (*M* = 36, *SD* = 11); *t*(52) = 4.39, *p* < .001). Participants in the worry condition reported that the selected future event was highly personal, and reported that on average they spent about 67% of the time thinking about their personal topic at post manipulation. There were no condition differences in ratings of relevance, *t* (52) = 1.38, *p* = .17, or on time spent thinking about their personal topic, *t* < 1, *NS*. At the end of the experiment, participants in the worry condition were still significantly more worried, less relaxed, more anxious, and less happy compared to participants in the control condition: all *t*s > 3.7, all *p*s < .01 (see Table 1).

Table 1. Mean VAS scores at pre-manipulation, post-manipulation and at the end of the task for worry and control conditions. SDs are reported in parenthesis.

	Pre-manipulation		Post-manipulation		After the Task	
	Control group	Worry group	Control group	Worry group	Control group	Worry group
Worry Ratings	28 (26)	28 (24)	21 (19)	55 (24)	17 (16)	46 (22)
Relax Ratings	66 (24)	57 (31)	79 (17)	51 (20)	77 (17)	56 (25)
Happy Ratings	71 (18)	70 (19)	82 (14)	59 (23)	80 (17)	60 (24)
Anxiety Ratings	26 (25)	26 (24)	19 (22)	52 (22)	17 (22)	42 (21)

Change Detection Task

The worry and control condition did not significantly differ from each other on WMC prior to the experimental manipulation, $t < 1$, *NS* (Worry: $M = 1.42$, $SD = .76$; Control: $M = 1.53$, $SD = 1.05$). Furthermore, participants did not differ from each other based on the location they were recruited from (UK or Belgium) in terms of WMC at pre-manipulation, post-manipulation or pre to post change scores (all *t*s < .1, *NS*).

Results of the bias-corrected bootstrapping procedure showed that the indirect effect of condition on change in WMC via worry was significant (path *ab*, $b = -.41$; boot 95% CI = [-1.0632, -.0001]) with medium-to-large effect size ($K^2 = .18$, boot 95% CI = [.0204, .4162]; Preacher & Kelley, 2011). The direct effect (path *c′*, $b = .06$, $t(51) < 1$) was not significant. The total effect (path *c*, $b = -.35$, $t(52) = -1.47$, $p = .15$) did not reach significance. These results indicate that worry mediated the relationship between condition and change in WMC. Figure 3a shows the relationship between the level of worry and the change in WMC in each condition.

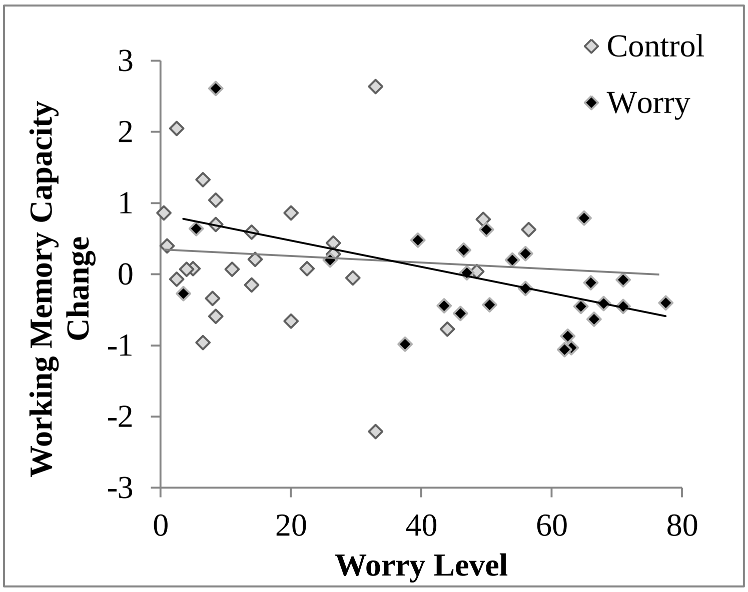
Results of the bias-corrected bootstrapping procedure also showed significant indirect effects of condition on change in WMC via VAS Anxiety level (path *ab*, *b* = -.48; boot 95% CI = [-1.0429, -.1484] and via STAI-SA (path *ab*, *b* = -.26; boot 95% CI = [-.8254, -.0519] separately. Both effects represented medium-to-large effect sizes (for VAS Anxiety level, K^2 = .24, boot 95% CI = [.0766, .4537]; for STAI-SA, K^2 = .14, boot 95% CI = [.0325, .3360]; Preacher & Kelley, 2011). The direct effects were not significant in either of the analyses (path *c′,* all *t*s < 1, *NS*). Results indicate that the level of state anxiety scores assessed via VAS anxiety and also STAI-SA mediated the relationship between condition and WMC change (See figure 3b –for VAS anxiety level- and 3c –for STAI-SA- for the relationship between state-anxiety and change on WMC in the worry and control conditions separately) [3].

It is noteworthy to mention that our mediation model did not fit the criteria of traditional full mediation model where the total effect should be significant (Baron & Kenny, 1986). However, recent theoretical approaches on mediation analyses (Mathieu & Taylor, 2006; Hayes, 2009) have offered new insights into the validity of mediation where the significance of the total effect is no longer a prerequisite, usually referred to as an indirect effect model (Mathieu & Taylor, 2006). In an indirect effect model, a significant indirect effect is expected while the direct effect is not significant and the pre-requisite of the significance of the total effect is not required. This model indicates that the independent variable influences the dependent variable only through an intervening factor.

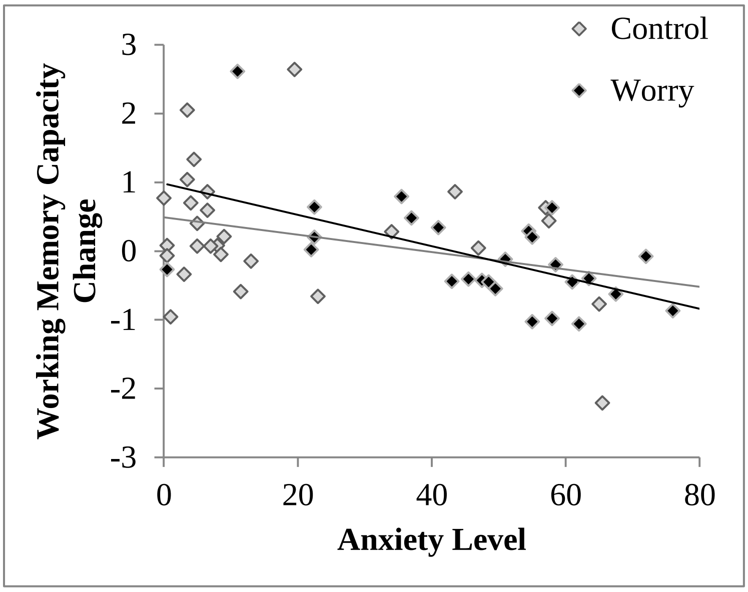
[3] Mediation analyses with condition as an independent variable, change scores in WMC as a dependent variable and the level of worry as intervening factor in the distractor condition (*b* = −.0580; boot 95% CI = [−.3724, .1774]) and two-item condition (*b* = −.1227; boot 95% CI = [−.2923, 0801]) did not lead to significant indirect effects.

Figure 3. (a) Relationship between the level of worry and the change in WMC in each condition. (b) Relationship between the level of anxiety and the change in WMC in each condition. (c) Relationship between STAI-SA scores and the change in WMC in each condition.

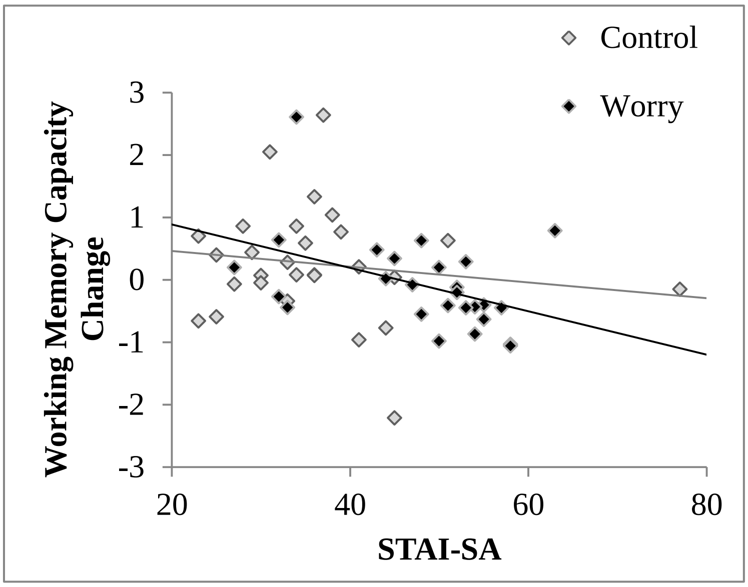
(a)



(b)



(c)



Additional analysis

We also assessed the relationship between the time participants spent thinking about their personal topic and change in WMC. In the worry condition, correlational analysis indicated a negative relationship between these variables ($r(26) = -.54$, $p < .01$) suggesting that the time participants spent thinking about their personal topics was associated with smaller improvements in WMC. This relationship was not found in the control condition ($r(28) = .08$, $p = .68$). These two correlation coefficients differed from each other significantly (Fisher's $z = 2.38$, $p < .05$).

DISCUSSION

The purpose of the present study was to investigate the direct influence of active worry on WMC. In keeping with the predictions of the ACT (Eysenck et al., 2007), active worry was expected to reduce processing efficiency and lead to reduced WMC. The results were in line with that prediction. Our mediation model found that levels of active worry mediated the relationship between condition and changes in WMC indicating that worrying interfered with improvements in WMC. Furthermore, the time participants spent thinking about their personal topic was also related to smaller improvements in WMC in the worry condition. These results are among the first to demonstrate a direct effect of active worrying on a measure of WMC and in this sense have direct implications for theories of anxiety and worry (e.g., Eysenck et al., 2007; Berggren & Derakshan, 2013; Hirsch & Mathews, 2012) that attempt to understand the main mechanism by which anxiety related effects impair performance outcome(s). Accordingly, our results showed that worrying likely depletes resources of working memory that are needed for efficient task performance providing the first direct support for one of the main predictions of the ACT (Derakshan & Eysenck, 2009).

In recent research, it has been demonstrated that high levels of trait susceptibility to worry are associated with reduced attentional control in the presence of threat related distractors (Stout et al., 2015; Owens et al., 2015) with other work showing that active worrying can have a detrimental effect on working memory performance in a healthy population (Hayes et al., 2008) as well as in GAD patients (Stefanopoulou et al., 2014). Our results extend these findings by shedding light on a mechanism by which worrying can adversely affect working memory through its influence on WMC. Interestingly, in line with previous work (e.g., Stout et al., 2015) our results showed that higher levels of anxiety were also related to greater detriments on WMC. Impaired WMC using the CDT in anxiety has also been documented elsewhere (Qi, Chen, Hitchman, Zeng, Ding, Li, & Hu, 2014). In this study, Qi et al. (2014) observed reduced WMC at the neurophysiological level for high anxious participants suggesting disrupted processing efficiency by anxiety. This result was more evident when the task was more difficult and higher WMC was required. The authors explained these results in terms of elevated worry due to a stressful situation (task difficulty) in high anxious individuals.

Understanding the influence of worry on processing efficiency is valuable for educational as well as clinical reasons. An important implication of these results can be found in academic and evaluative conditions where worrying can have serious and severe (deleterious) effects on cognitive performance outcome(s) through its direct depletion of WMC leading to adverse consequences on academic achievement levels that are dependent upon WMC (Owens, Stevenson, Hadwin, & Norgate, 2012). Accordingly, results of the current study show that worrying can harm WMC and in situations such as academic evaluations where WMC resources are needed for task demands it can exert a direct detrimental effect on outcomes. Secondly, excessive worrying is one of the main characteristics of mood and anxiety disorders (Hirsch & Mathews, 2012; Nolen-Hoeksema, 1991). Hence, clarifying the role of worry on processing efficiency and WMC would help to gain greater insight into the cognitive risk factors of onset and maintenance of these disorders. According to recent models of working memory (see Shipstead et al., 2014; Gazzaley & Nobre, 2012), WMC and attentional control are highly inter-linked at a conceptual as well as a measurement level. Given the wealth of accumulating evidence documenting attentional control deficits in anxiety, the investigation that reduced WMC can explain the onset and recurrence of anxiety related symptomatology is imperative to developing clinical models of anxiety that are keen to understand the causal mechanisms behind anxiety related disorders. In this respect, there is an increasing interest in targeting working memory through adaptive cognitive training regimes meant to establish not only plasticity induced changes in cognitive function (Owens et al., 2013) but also training-dependent reductions in anxious symptomatology over time (e.g., Sari, Koster, Pourtois, & Derakshan, 2015). The current findings motivate the targeting of WMC to reduce the effects of worry related thoughts on a wide range of behavioral outcomes.

The present study established that worrying can cause disruptions to WMC. Interestingly, condition did not influence WMC directly but through the levels of state worry and anxiety implying the importance of individual differences in emotional reactivity. This might be related to trait factors like trait anxiety. However, the current study did not investigate the role trait worry/anxiety. In a related manner, given the vast evidence on attentional bias towards negative emotional stimuli being conceived as a well-known vulnerability factor for anxiety (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & Van Ijzendoorn, 2007) active worrying might be related to increased attentional bias towards threat, as well as hypervigilance for threat (see Eysenck, 1992) leading in turn to detriments to performance. To this end, future studies are recommended to examine how worrying can increase attentional bias for threat through reducing WMC. Furthermore, here we found that both state anxiety and worry were related to impairments in working memory. Since worry is described as a cognitive component of anxiety (Mathews, 1990), it is not surprising that increased level of worry led to elevated anxiety and similar results were observed both for worry and anxiety. Given the high correlation between worry and anxiety it is impossible to conclude that the effect observed on WMC is specific only for worry. Thus, although this study was framed in terms of worry capturing attentional resources and impairing working memory storage, other mechanisms could also be at play. For instance, anxiety or heightened arousal may have an influence on working memory as increased anxious arousal was associated with impaired spatial working memory (Shackman, Sarinopoulous, Maxwell, Pizzagalli, Lavric, & Davidson, 2006; Lavric, Rippon & Gray, 2003). Future studies could focus on this distinction in order to understand the unique role of worry on working memory in situations where anxiety and worry are less entangled. Another limitation of the current study was limited sample size. In order to obtain stable confidence intervals in our sample size, the number of bootstrap samples had to be increased.

In conclusion, the current study provides further evidence that worrying can reduce WMC. This suggests a mechanism by which the detrimental effects of anxiety and worry on performance outcome can be explained.

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CHAPTER 5

THE EFFECTS OF ACTIVE WORRYING ON THREAT-RELATED INFORMATION PROCESSING CONSIDERING THE MODULATORY ROLE OF WORKING MEMORY CAPACITY[1]

ABSTRACT

Worry is usually conceived as the cognitive component of anxiety that is closely associated with threat-related biases in attention (Hirsch & Mathews, 2012), but the mechanisms underlying the effects of this key component on attentional processes as well as more fundamental executive functions such as attentional control and working memory capacity (WMC) are currently not well understood. In this respect, high WMC, and the ability to resist distractor interference (Barrett et al., 2004), can potentially reduce the effect of worry-related impairments on performance. The current study investigated the influence of worry on attentional bias to threat and examined the possible moderating role of WMC therein. For this purpose, participants first performed a change detection task (with neutral stimuli) where WMC was assessed. Then they were assigned either to worry (N = 49) or control (N = 49) condition. Participants in the worry condition were asked to think of a personally relevant worrisome concern and participants in the control condition were asked to think of a personally relevant positive event. After the worry/control manipulation, participants performed a visual search task with happy, angry and neutral faces to investigate threat-related attentional bias. We predicted that (1) participants in the worry condition would have greater attentional bias to threat during the visual search task than the participants in the control condition; and (2) WMC would moderate the relationship between condition (worry vs control) and attentional bias, specifically, high-WMC participants would exhibit less attentional bias to threat. However, results failed to find an effect of worry (vs control) on visual search task performance, and WMC did not moderate the relationship between worry and attentional bias. Implications of these findings, limitations and future directions are discussed within the framework of current theoretical models of worry and anxiety.

[1] Sari, B. A., Derakshan, N., Pourtois, G., & Koster, E.H. (2016). The effects of active worrying on threat-related information processing considering the modulatory role of working memory capacity. *Unpublished manuscript.*

INTRODUCTION

Worry is described as a state of having uncontrollable, intrusive, negative thoughts about the future (Borkovec, Robinson, Pruzinsky, & DePree, 1983). It is a crucial cognitive component of anxiety that is closely related to attentional biases toward threat (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van Ijzendoorn, 2007) which may occupy the limited attentional resources leading to impaired task performance (Mathews, 1990; Eysenck, Derakshan, Santos & Calvo, 2007; Hirsch & Mathews, 2012). However, previous research suggested that some individuals are better able to ignore distracting information by recruiting high-level cognitive processes such as attentional control and working memory capacity (Derryberry & Reed, 2002; Barrett, Tugade, & Engle, 2004). This suggests that better attentional control and working memory capacity can also reduce the susceptibility to threat-related distraction and attentional biases. The current study sought to examine this issue in greater detail.

Attentional bias in high anxiety is usually characterized by facilitated engagement towards threat-related stimuli and also impaired disengagement from such stimuli (Cisler, Bacon, & Williams, 2009; Cisler & Koster, 2010). Besides being preferentially biased toward threat, there is also ample evidence that associates anxiety with high worry. According to the cognitive model of pathological worry (Hirsch & Mathews, 2012), biased attention can play an important role in the onset (i.e. engagement with threat) and maintenance (i.e. difficulties to disengage from threat) of worry, with reciprocal links between worry and attentional bias. In line with this prediction, several studies previously showed that when attentional bias toward threat is induced, so is increased vulnerability to worrisome thoughts (Hirsch, MacLeod, Mathews, Sandher, Siyani, & Hayes, 2011; Krebs, Hirsch, & Mathews, 2010). The reverse effect has also been documented in the literature in the past. For example, the influence of worrying on threat-related attentional bias processes was observed in a study by Oathes, Squillante, Ray, and Nitschke (2010). In that study, participants were asked to think of a worrisome concern in the worry condition; and performed mental arithmetic in the control condition. Then they performed a dot-probe task with threat-related and neutral words. Oathes et al. (2010) observed increased attention to threat-related words during the dot-probe task after the worry induction procedure. Collectively, these studies demonstrate a close link between worry and threat-related attentional biases. However, individual differences in high-level cognitive processes (i.e. working memory capacity; WMC) can presumably also play an important role in the interference of attentional capture by threat (Derryberry & Reed, 2002; Barrett et al., 2004; Stout, Shackman, & Larson, 2013). Nonetheless, it is currently unclear whether the link between worry and attentional bias is modulated by individual differences in high-level cognitive functions. Therefore, the current study sought to fill this gap by examining how this relationship (i.e., worry and attentional bias to threat) may be modulated by WMC, as WMC is a critical cognitive construct which is strongly related to various cognitive abilities (Luck & Vogel, 2013), such as attentional control (Shipstead, Lindsey, Marshall, & Engle, 2014) and general fluid intelligence (Kane, Hambrick, & Conway, 2005).

Working memory is a limited capacity cognitive system which is essential to perform complex tasks (Baddeley, 1992). The capacity of working memory is determined greatly by one’s ability to process task-relevant information while resisting distractor interference (Shipstead, Harrison, & Engle, 2012). Several studies already demonstrated that trait vulnerability to worry is associated with impaired filtering of threat-related distracters from working memory (Stout, Shackman, Johnson, & Larson, 2015; Owens, Derakshan, & Richards, 2015). However, in these studies, WM performance and threat-related information processing were investigated within the same task, making it difficult to distinguish the role of individual differences in WMC on reducing threat interference. Furthermore, these studies mainly focused on trait vulnerability to worry, yet the influence of active worrying where worry-related effects on performance can be directly observed (i.e. Hayes, Hirsch, & Mathews, 2008; Sari, Koster, & Derakshan, 2016) was not examined systematically in these earlier investigations. Therefore, the current study experimentally induced worry and examined its effect on selective attention to threat considering the role of WMC; using two different tasks meant (1) to assess WMC; and (2) to measure threat-related attentional bias.

In the present study, in order to assess WMC, a change detection task with neutral stimuli (rectangles) was used (Vogel, McCollough, & Machizawa, 2005). During this change detection task, participants are briefly shown two or four rectangles and instructed to monitor changes in the orientation of these rectangles from the initial display to a second display. Change detection task is considered a valid instrument to assess WMC (Luck & Vogel, 1997; Vogel et al., 2005; Shipstead, Harrison, & Engle, 2015). In this task, individuals with high WMC are expected to show high performance regardless of the set-size (i.e. two or four rectangles); whereas individuals with a low WMC are likely to show performance decrements as the set-size increases.

To examine threat-related attentional bias, a visual search task (i.e. Öhman, Flykt, & Esteves, 2001) with emotional (happy, neutral or angry) faces was used. In the visual search task, participants are shown several faces forming a circle or array. These faces have either all the same facial expressions (target-present trials; i.e. all happy faces) or one of them has a different facial expression (target-absent trials; i.e. one angry face among happy faces; all combinations are possible). Participants are asked to respond if they detect a face with a different facial expression (odd one out), as fast as possible. Based on their response times, indices with regard to attentional engagement (i.e. how fast participants detect an angry face among neutral faces as compared to a happy face among the same neutral faces) and attentional disengagement (i.e. how fast participants detect a neutral face among happy faces as compared to a neutral face among angry faces) were calculated. Higher scores on these indices indicate biased attention in favor of threat-related (angry faces) stimuli. In order to examine the influence of active worrying on threat-related attentional processes, a worry/control manipulation (cf. Hayes et al., 2008) was applied before the visual search task. During this manipulation, participants in the worry condition were asked to specify a personally relevant worrisome concern, and in the control condition participants were asked to specify a personally relevant positive future event. Afterwards, they were asked to either focus the negative theme (worry condition) or positive event (control condition).

We examined the following set of hypotheses: We expected that (1) participants in the worry condition would express a larger attentional bias to threatening information during the visual search task than the participants in the control condition; and (2) WMC would moderate the relationship between condition (worry vs control) and engagement/disengagement scores. Specifically, individuals with high WMC were expected to be able to better control their attentional bias to threat.

METHOD

Participants

Ninety-eight participants (25 males) aged between 18-49 years (*M* = 24 years, *SD* = 6) were recruited from the campus of Birkbeck University of London (*N* = 31) and University of Ghent (*N* = 67). They were compensated 5 GBP/5 Euro or given course credit for their participation. The first participant was randomly assigned to either worry (*N* = 49) or control (*N* = 49) condition and subsequent participants were assigned to the different conditions alternatingly. Data from 9 participants were removed due to poor accuracy on the change detection task, less than 50% accuracy, *N* = 6; poor accuracy on the visual search task, less than 50% accuracy, *N* = 2; missing target-absent trials in visual search task, more than 50%, *N* = 1; leaving 89 individuals (46 in the 'Worry' and 43 in the 'Control' condition) in the final sample.

Materials and Procedure

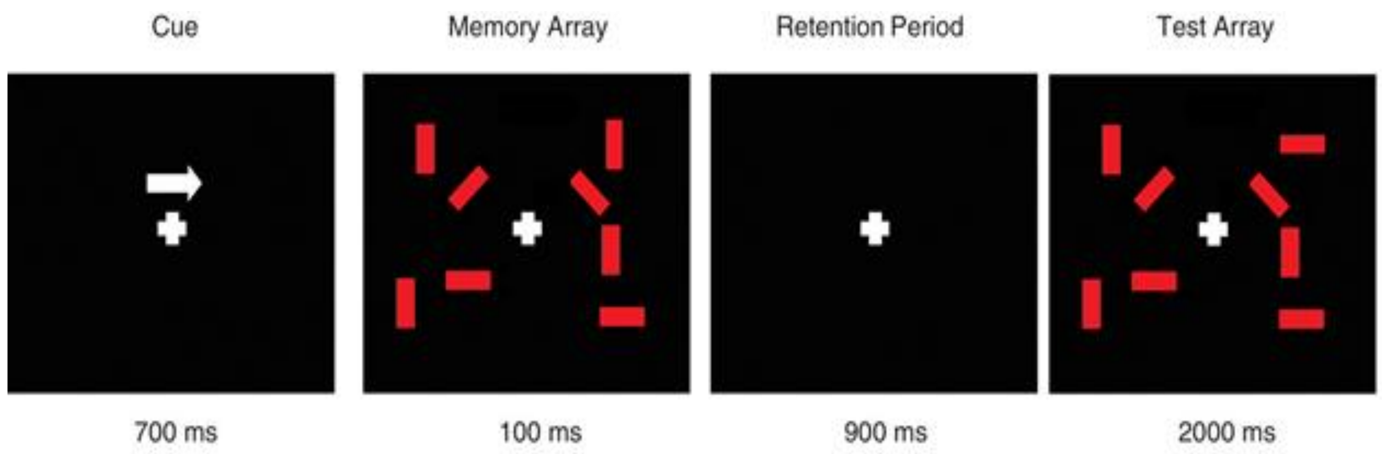
Questionnaires. Trait anxiety was assessed using the trait version of State Trait Anxiety Inventory (STAI-TA; Spielberger, Gorsuch, Lushene, Vagg & Jacobs, 1983). The STAI-TA is a well-validated 20 item self-report instrument (Spielberger & Reheiser, 2004). Respondents indicate the degree to which they experience each of the items on four-point scale (1="almost never" to 4="almost always"). Trait worry was assessed via Penn State Worry Questionnaire (PSWQ; Meyer, Miller, Metzger, & Borkovec, 1990). PSWQ is 16-item self-report measure with five-point scale (1 = "not at all typical of me" to 5 = "very typical of me"). The PSWQ demonstrates good psychometric properties (Meyer et al., 1990; Startup & Erickson, 2006). Lastly, the Ruminative Responses Scale (RRS; Nolen-Hoeksema & Morrow, 1991) was administered to measure trait rumination. The RRS is a 22 item self-report measure with a four-point scale (1="almost never" to 4="almost always") containing items with regard to two subcomponents of rumination: brooding and reflection (Treynor, Gonzalez, & Nolen-Hoeksema, 2003). RRS also possess satisfactory psychometric properties (Treynor et al., 2003). During the experiment, state worry and state anxiety levels were assessed via 0 – 100 mm visual analogue scales (VAS; 0 = "not at all" to 100 = "extremely"). VAS is considered a valid and reliable instrument to assess state anxiety (Rossi & Pourtois, 2012).

Change Detection Task. Figure 1 shows a schematic overview of a trial sequence. Each trial started with a fixation cross and an arrow above pointing either right or left (700 ms). Participants were asked to attend to the side of the screen indicated by this arrow. Afterwards, either 2 or 4 rectangles appeared at the right and left side of the screen (3° away from the fixation cross; within a region of 4° x 7.2°; memory array; 100 ms). Participants were instructed to memorize the orientation of the red rectangles on the attended side. After a brief retention period (900 ms), the rectangles appeared again on the right and left side of screen (test array, 2000 ms or until the response). In this array, participants were asked to indicate whether the orientation of one of the red rectangles at the attended side had changed or not (i.e., two-alternative forced choice task).

There were three conditions in this task: two-item, four-item, and distractor conditions. In the two-item and four-item conditions, all rectangles were red while in the distractor condition, there were two blue distracting rectangles in addition to two red rectangles. Rectangles appeared on random positions with a minimum of 2° distance from each other. There were 4 possible orientations: vertical, horizontal, 45° left and 45° right tilted. Matching these criteria, 98 stimulus sets were used for the four-item, 105 stimulus sets for the two-item and 101 stimulus sets for the distractor condition. All possible conditions were randomly presented within the task.

The task had 4 experimental blocks consisting 48 trials in each. Participants practiced the task until they performed above 50% correct.

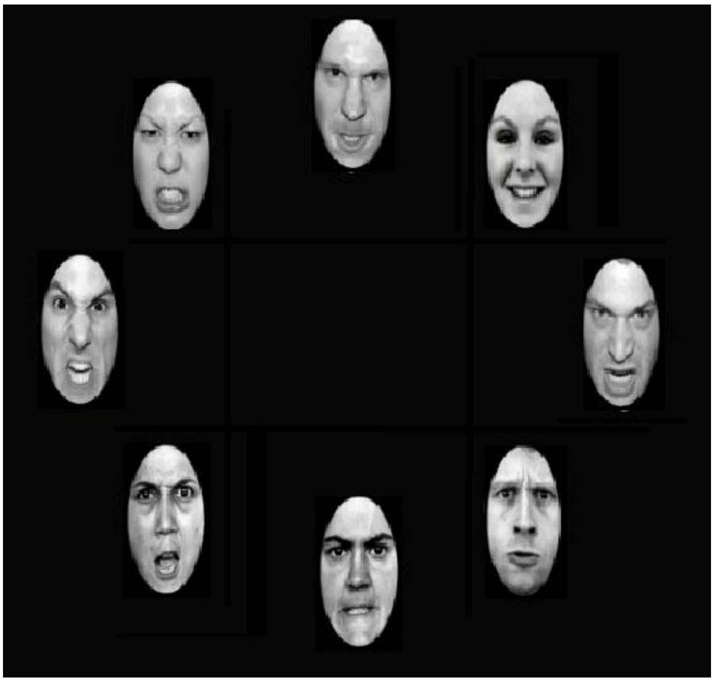
Figure 1. Example of a 4-item condition in a change trial. Participants are instructed to remember the orientations of the rectangles, and respond during the test array to indicate whether a change occurred or not.



Visual Search Task. Each trial started with a fixation cross (1250 ms). Following the fixation cross, eight faces (2 º29’ x 4 º29’) forming a circle were presented (Figure 2). Each of the faces was 8 º15’ away from the center of the circle. These faces were depicting neutral, happy or angry expressions (12 face identities; 6 males, 6 females; Ekman & Friesen, 1976; Lundqvist, Flykt, & Öhman, 1998).

There were two different types of trial in this task: target-present trials and target-absent trials. In the target-present trials, while 7 of the faces (crowd) had the same facial expression, 1 face (target) had a different facial expression. Each facial expression was presented both as crowd and target. Fitting this criteria, there were 6 target/crowd pairs: Neutral/Happy, Neutral/Angry, Happy/Neutral, Happy/Angry, Angry/Happy, Angry/Neutral. There were 24 trials for each of these pairs and 144 target-present trials in total. Additionally there were 36 target-absent trials where all faces had the same facial expressions (12 trials for each facial expression). Participants were instructed to press the indicated button, as fast as possible when they had detected a face with a different expression during the target-present trials, but wait until the end of the trial without pressing any button during the target-absent trials. Each trial was presented for 5000 ms or until the response. All possible conditions were randomly presented during the task.

Figure 2. Example of a happy face in an angry crowd in visual search task.



Procedure. Participants first read and signed the consent form. Then, they filled in questionnaires. After the questionnaires, they performed the change detection task. Subsequently, they provided mood ratings (with regard to worry, anxiety, happiness, relax) using VAS (pre-manipulation). Afterwards, they were asked to think of a personally relevant future event about which they felt worried (worry condition) or positive (control condition). They were also shortly interviewed by the experimenter (~2 minutes) about the positive (control condition) or negative (worry conditions) aspects of these events (cf. Hayes et al., 2008; Sari et al., 2016). Once the interview was over, participants were asked to keep thinking about these events until the end of the experiment. Then they filled in VAS for the second time (post-manipulation). They were also asked to rate about the personal relevance of the events they described. Afterwards, they performed visual search task. At the end of visual search task, participants provided VAS mood ratings one more time (after the task). In the last VAS, participants were also asked to indicate how often they thought about the future event they described at the beginning of the experiment.

Data Reduction and Analytic Approach. In order to assess the performance on the change detection task, we calculated WMC using a typical formula (Pashler, 1988): K = S x (H - F)/(1-F) where K represents WMC, S is the set size to remember, H is observed hit rate and F is false alarm. In keeping with several studies using change detection task (Lee, Cowan, Vogel, Rolan, Valle-Inclan, & Hackley, 2010; Owens, Koster, & Derakshan, 2013; Sari et al., 2016), we used K scores only for four-item condition. We did not include the two-item condition or distracter condition since these are susceptible to possible ceiling or floor effects.

For the visual search task, analyses were conducted on correct target-present trials (< 3% of the data was excluded due to errors). Trials deviating more than 3 *SD* from the individual mean RT were also discarded (< 1%). Next, we calculated engagement (1) and disengagement (2) scores separately based on mean RTs in trials with neutral target or neutral crowd:

(1) Engagement scores were calculated by subtracting mean RTs for Angry Target/ Neutral Crowd trials from Happy Target/Neutral Crowd trials (Happy/Neutral – Angry/Neutral).

(2) Disengagement scores were calculated by subtracting mean RTs for Neutral Target/Happy Crowd trials from Neutral Target/Angry Crowd trials (Neutral/Angry – Neutral/Happy).

Higher scores in these indexes indicated greater attentional bias towards negative faces.

We first investigated whether condition had an effect on mean RTs for the trial types used to calculate engagement scores by means of a 2 (Angry Target/ Neutral Crowd trials vs Happy Target/Neutral Crowd trials) x 2 (control vs worry) ANOVA. A similar analysis was also repeated for the mean RTs for the trial types used to calculate disengagement scores: a 2 (Neutral Target/ Angry Crowd trials vs Neutral Target/Happy Crowd trials) x 2 (control vs worry) ANOVA was used. Next, we investigated (1) whether condition (worry vs control) or WMC had an effect on engagement/disengagement scores; and (2) whether WMC moderated the relationship between the condition and engagement or disengagement via moderation analyses. These analyses were conducted using IBM SPSS 19 and the macro PROCESS 2.13.2 (Hayes, 2013). Results are reported by means of regression coefficients. Variables were mean centered and controlled for heteroscedasticity.

RESULT

Group Characteristics

Questionnaires. Participants in the Worry and Control conditions did not significantly differ from each other on STAI-TA, PSWQ or RRS (all *t*s < 1.35, *NS*). Conditions also did not significantly differ from each other in terms of age ($t < 1$, *NS*) or gender distribution ($X^2(1, N = 89) = .01, p = .94$).

Mood induction Check. There were no condition differences on any of the mood ratings before the worry/control manipulation (pre-manipulation; all *t*s < 1.2, *NS*; see table 1 for descriptive statistics). As expected, participants in the worry condition were more worried, less relaxed, more anxious, and less happy than the participants in the control condition (all *t*s > 7, all *p*s <.001) after the manipulation (post manipulation). Participants also reported that the future events they described were highly personal (85%) and on average they spent 61% of the time thinking about these events throughout the experiment (when asked at post manipulation). There were no significant condition differences in ratings of relevance, t (87) = 1.78, p = .08[2], or on time spent thinking about their personal concern, t < 1, *NS*. At the end of the experiment, participants in the worry condition were still significantly more worried, less relaxed, more anxious, and less happy compared to participants in the control condition (all ts > 4, all ps < .001).

Table 1. Mean VAS ratings at pre-manipulation, post-manipulation and after the task for worry and control conditions. SDs are reported in parenthesis.

	Pre-manipulation		Post-manipulation		After the Task	
	Control condition	Worry condition	Control condition	Worry condition	Control condition	Worry condition
Worry Ratings	27 (24)	32 (28)	23 (19)	64 (22)	24 (19)	51 (25)
Relax Ratings	62 (21)	57 (26)	72 (22)	35 (19)	65 (19)	45 (22)
Happy Ratings	65 (20)	66 (20)	79 (17)	38 (19)	68 (21)	50 (21)
Anxiety Ratings	31 (25)	32 (24)	26 (23)	58 (20)	27 (23)	50 (22)

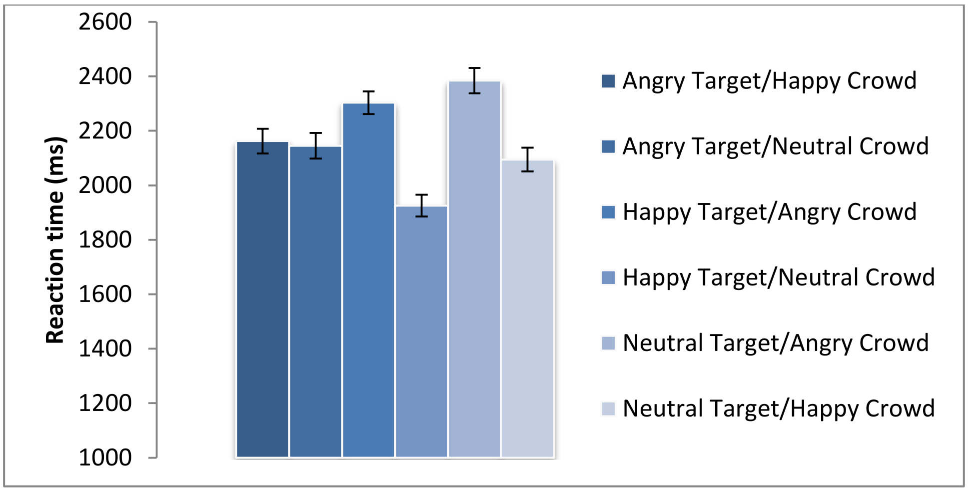
Change Detection Task. The worry and control conditions did not significantly differ from each other in their levels of WMC, t < 1, *NS* (worry condition, M = 1.59, SD = .82; control condition, M = 1.45, SD = .80). Participants also did not differ from each other based on the location they were recruited from (either UK or Belgium) in terms of WMC (t < 1, *NS*).

Visual Search Task

Performance did not differ based on the location participants were recruited from (UK or Belgium) in terms of engagement (t < 1, *NS*), or disengagement (t < 1, *NS*). Mean reaction times for each target/crowd pairs are presented in Figure 3.

[2]In the worry condition, there was one participant who had a very low rating (22%) about the personal relevance of worrisome event. Excluding this participant, worry and control conditions were still not different from each other in terms of personal relevance ratings, t(86) = 1.49, p = .14. Furthermore, inclusion or exclusion of this participant did not change the results of the further analyses either.

Figure 3. Mean reaction times for each target/crowd pairs in visual search task (bars indicate standard errors).



Engagement. The 2 X 2 ANOVA with trial type (Angry Target/ Neutral Crowd vs Happy Target/Neutral Crowd) and condition (control vs worry) showed a significant main effect of trial type only ($F(1, 87) = 83.33$, $p < .001$) indicating slower RTs in Angry Target/ Neutral Crowd trials ($M = 2146$, $SD = 447$) as compared to Happy Target/Neutral Crowd trials ($M = 1925$, $SD = 380$). Main effect of condition or trial type x condition interaction did not reach significance ($F <1$, *NS*).

Disengagement. The 2 X 2 ANOVA with trial type (Neutral Target/Angry Crowd trials vs Neutral Target/Happy Crowd trials) and condition (control vs worry) showed a significant main effect of trial type only ($F(1, 87) = 126.06$, $p < .001$) indicating slower RTs in Neutral Target/Angry Crowd trials ($M = 2385$, $SD = 432$) as compared to Neutral Target/Happy Crowd trials ($M = 2095$, $SD = 406$). Main effect of condition or trial type x condition interaction did not reach significance ($F <1$, *NS*)[3].

[3]Considering inter-individual differences in mood manipulation, we also conducted correlational analyses between engagement/disengagement scores and averaged VAS worry ratings at post-manipulation and at the end of the task (cf. Sari et al., 2016). These analysis did not reveal any significant relationship between the average VAS worry ratings and engagement ($r(89) = -.06$, $p = .61$); or disengagement scores ($r(89) = -.04$, $p = .71$).

Moderation Analyses. Results from the moderation analyses showed that neither condition nor WMC had significant effects on visual search task performance (either engagement or disengagement scores); and there was no significant moderating effect of WMC on the relationship between condition and visual search task performance. Effect of condition, WMC and condition x WMC interaction (which refers to moderating effect of WMC on the relationship between condition and visual search task performance) on engagement/disengagement are reported in table 2.

Table 2. Linear model of predictors of Engagement and Disengagement scores.

ENGAGEMENT

	b	*SE B*	*t*	*p*
Constant	-218.94	24.37	-8.98	*p* < .001
WMC	26.18	29.2	0.9	*p* = .37
Condition	-6.65	48.88	-0.14	*p* = .89
WMC x Condition	40.45	58.45	0.69	*p* = .49

DISENGAGEMENT

	b	*SE B*	*t*	*p*
Constant	288.83	26.34	10.97	*p* < .001
WMC	37.92	34.98	1.08	*p* = .28
Condition	-26.42	52.77	-0.5	*p* = .62
WMC x Condition	23.42	70.55	0.33	*p* = .74

DISCUSSION

In this study, we focused on the role of active worrying on threat-related information processing considering the possible modulatory role of WMC therein. We predicted that worrying would be related to greater attentional bias to threat during visual search task and that WMC could moderate this relationship. Specifically, we hypothesized that high WMC would be related to reduced attentional bias in the worry condition. Our results showed that condition (worry, control) was not related to any of the attentional bias indices (either engagement or disengagement) in visual search task. Furthermore, WMC did not moderate the relationship between condition and visual search task performance either. These null findings are further discussed below.

In the current investigation, contrary to what is suggested in prominent theories of worry and anxiety (Eysenck, 1992; Hirsch & Matthews, 2012; Eysenck et al., 2007), we failed to show increased attentional bias towards threat-related stimuli in relation to induced worry. However, there have been previous studies showing that anxiety, but not worry, was related to impairments in attentional control (Forster, Elizalde, Castle, & Bishop, 2013), or distractor inhibition (Moser, Becker, & Moran, 2012). Based on their results, Moser et al. (2012) suggested that attentional capture by salient stimuli may not be directly related to the worry component of anxiety (but see Stout et al., 2014).

The influence of worry on behavioral performance might also have gone undetected with the measures selected in our study (tapping primarily into effectiveness as opposed to efficiency), indirectly supporting processing efficiency accounts in anxiety; such as the processing efficiency theory (Eysenck & Calvo, 1992) and the attentional control theory (Eysenck et al., 2007). According to these theories, anxiety mainly impairs processing efficiency (relationship between the performance outcome and the active use of cognitive resources; often assessed via neurophysiological measures) rather than performance effectiveness (outcome, quality of the performance; often assessed via behavioral measures such as accuracy rates). In the current investigation, visual search task performance was assessed by response times, following standard practice. Several studies regarded response times as a measure of processing efficiency (i.e. Ansari, Derakshan, & Richards, 2008). However, this approach has been later criticized since response time is also a behavioral outcome which does not directly assess processing efficiency (Eysenck & Derakshan, 2011; Ansari & Derakshan, 2011; Basten, Stelzel, & Fiebach, 2012). Hence, more direct assessment techniques such as neurophysiological measures are recommended to investigate processing efficiency and more specifically how this variable is susceptible to worry induction (state anxiety) and effects of WMC. Accordingly, several studies previously reported anxiety-related impairments confined at the neurophysiological rather than the behavioral level (i.e. Qi et al., 2014a; Qi, Ding, & Li, 2014b). However, in the present study, we did not have any neurophysiological measure where worry-related effects could possibly be more evident. In line with this assumption, using a visual search task (with neutral, angry, happy faces) similar to the one used in the present study, Derakshan and Koster (2010) previously investigated the role of trait anxiety in threat-processing. Results of that study indicated that there was a response delay in relation to emotional faces; yet this emotion effect was not threat-specific. High anxious participants had delayed response in both happy target/angry crowd and angry target/happy crowd conditions. Hence, threat-related processes with regard to engagement and disengagement could not be distinguished based on response times.

The current study was conducted in unselected, healthy subjects. However, influences of induced worry on performance might have been more clearly observed among individuals with high trait vulnerability to worry or stress (see Stefanopoulou, Hirsch, Hayes, Adlam, & Coker, 2014; Owens et al., 2015). Furthermore, the worry induction procedure we used may also not be potent enough to observe strong and reliable worry-related effects on visual search task performance in healthy individuals (at the sub clinical level). Using a worry induction procedure, similar to the one used in the present study, Stefanopoulou et al., (2014) previously investigated the influence of active worrying on attentional control in GAD patients and healthy controls. In this study, Stefanopoulou et al. reported that GAD patients had more negative thoughts following the mood induction as compared to healthy controls.

Lastly, the current study also failed to observe modulatory effect of WMC on the relationship between condition (worry vs control) and processing of threat-related information (engagement/disengagement scores). Because the lack of (statistical) evidence does not necessarily prove the absence of evidence, caution is definitely needed regarding the interpretation of this null finding. We note however that we failed to reveal such as modulatory effect of WMC in the present case although the worry mood induction was found to be successful. We therefore conclude that it remains inconclusive if WMC truly exerts a reliable modulatory role in the complex interplay of worry with (threat-related) attentional biases.

In summary, the results of the current investigation failed to demonstrate a clear and significant relationship between worry and attentional bias towards threat. The possible moderating role of WMC on this relationship was not confirmed. Future studies are recommended focusing on the other component of anxiety (i.e., anxious arousal; Liebert & Morris, 1967; Heller & Nitschke, 1998) as well as neurophysiological measures underlying visual search task performance; and also considering pre-selection of participants (i.e. high trait worriers) in order to have a better understanding of modulatory effects of WMC on threat-related attentional biases expressed as a function of worry or anxiety.

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CHAPTER 6

TRAINING WORKING MEMORY TO IMPROVE ATTENTIONAL CONTROL IN ANXIETY: A PROOF-OF-PRINCIPLE STUDY USING BEHAVIORAL AND ELECTROPHYSIOLOGICAL MEASURES[1]

ABSTRACT

Trait anxiety is associated with impairments in attentional control and processing efficiency (see Berggren & Derakshan, 2013, for a review). Working memory training using the adaptive dual n-back task has shown to improve attentional control in subclinical depression with transfer effects at the behavioral and neural level on a working memory task (Owens, Koster & Derakshan, 2013). Here, we examined the beneficial effects of working memory training on attentional control in pre-selected high trait anxious individuals who underwent a three week daily training intervention using the adaptive dual n-back task. Pre and post outcome measures of attentional control were assessed using a Flanker task that included a stress induction and an emotional Antisaccade task (with angry and neutral faces as target). Resting state EEG (Theta/Beta ratio) was recorded to as a neural marker of trait attentional control. Our results showed that adaptive working memory training improved attentional control with transfer effects on the Flanker task and resting state EEG, but effects of training on the Antisaccade task were less conclusive. Finally, training related gains were associated with lower levels of trait anxiety at post (vs pre) intervention. Our results demonstrate that adaptive working memory training in anxiety can have beneficial effects on attentional control and cognitive performance that may protect against emotional vulnerability in individuals at risk of developing clinical anxiety.

[1] Sari, B. A., Koster, E. H., Pourtois, G., & Derakshan, N. (2015). Training working memory to improve attentional control in anxiety: A proof-of-principle study using behavioral and electrophysiological measures. *Biological Psychology*.

INTRODUCTION

Cognitive views on anxiety pose that deficits in attentional processes can causally contribute to the etiology and maintenance of anxiety (see Eysenck, 1992; Mogg & Bradley, 1998; Mathews & MacLeod, 2005 for reviews). Despite a wealth of findings and substantial progress in such research, it is still unclear whether attentional processes indeed play a causal role in anxiety (Van Bockstaele, Verschuere, Tibboel, De Houwer, Crombez, & Koster, 2014). In recent years, innovative methods have manipulated attentional processes to understand if there is a causal relationship between attentional processes and anxiety. So far, most research has focused on manipulating attentional bias which involves reducing exaggerated attention to fear-relevant information in anxiety (see Koster, Fox, & MacLeod, 2009). Based on theories of attentional control and anxiety (Eysenck, Derakshan, Santos, & Calvo, 2007) the current study is among the first to examine the effect of manipulating cognitive control on anxiety related distractibility and anxiety vulnerability at the behavioral and neural level. We start with a basic description of attentional control theory (ACT) and then explain the relevance of manipulating attentional control.

Attentional Control Theory

The attentional system can be divided into two sub-systems, a top-down (goal-directed, volitional) and bottom-up (stimulus-driven, reflexive) subsystem (Corbetta & Shulman, 2002). ACT (Eysenck et al., 2007) claims that anxiety impairs the balance between these subsystems by reducing the influence of top down, goal directed processes biasing the increased influence of bottom up, stimulus driven processes (Miyake, Friedman, Emerson, Witzki, Howerter, & Wager, 2000). Substantial evidence using a multitude of methods now shows that anxiety impairs the efficiency by which the main central executive functions of working memory, namely the inhibition, shifting and updating of information, guide goal-directed behavior, reducing attentional control (see Derakshan & Eysenck, 2009; Eysenck & Derakshan, 2011; Berggren & Derakshan, 2013, for reviews). Extending the main assumptions of ACT (see Berggren & Derakshan, 2013), it seems that establishing a causal mechanism by which impaired attentional control can exacerbate anxiety's effects on performance outcome(s) through its emphasis on attention and maintenance on worrisome and ruminative thoughts, is imperative. A direct impact of reduced attentional control is the 'hidden' cost of compensatory processes that serve to maintain performance outcomes in high anxious individuals (e.g., Ansari & Derakshan, 2011a, Basten, Stelzel, & Fiebach, 2011, 2012; Righi, Mecacci, & Viggiano, 2009) exaggerating in turn the effects of anxiety on processing efficiency.

Recent theoretical accounts indicate a strong link between attentional control and working memory (see, Shipstead, Lindsey, Marshall, & Engle, 2014) as successful operation of working memory requires efficient use of attentional control in order to suppress task irrelevant information while processing goal-relevant information. Recent findings (e.g., Qi, Chen, Hitchman, Zeng, Ding, Li, & Hu, 2014) have confirmed the long standing assumption (see Derakshan & Eysenck, 1998) that anxiety is associated with reduced working memory capacity. Working memory can possibly mediate the relationship between anxiety and cognitive performance (Qi, Zeng, Luo, Duan, Ding, Hu, & Hong, 2014; Owens, Stevenson, Hadwin, & Norgate, 2012), with impairments in working memory capacity exaggerating the effects of anxiety on cognitive performance (Wright, Dobson, & Sears, 2014).

Manipulating attentional control

Adaptive cognitive training paradigms using the dual n-back training paradigm (Jaeggi, Seewer, Nirkko, Eckstein, Schroth, Groner, & Gutbrod, 2003) have been successful in improving a number executive processes such as general fluid intelligence (Au, Sheehan, Tsai, Duncan, Buschkuehl, & Jaeggi, 2014), inhibition and working memory capacity (Owens, Koster, & Derakshan, 2013) and cognitive control (Schweizer, Grahn, Hampshire, Mobbs, & Dalgleish, 2013), with training-related gains on untrained tasks measuring similar (near transfer) or different (far transfer) processes (but see Shipstead, Redick, & Engle, 2012). The adaptive dual n-back task is a working memory task where two streams of information – visual and auditory - need to be processed simultaneously. In this task, participants are asked to indicate whether there has been a match either for the visual or auditory information between the current trial and a number (*n*) trials back in the series. The task can get progressively more difficult with the level of '*n*' increasing as participant performance improves, thus providing an adaptive training. Such adaptive cognitive training techniques hold important implications for improving clinical outcome(s) in emotionally vulnerable populations. For example, Owens et al. (2013; see also Schweizer et al., 2013) using a dual n-back task investigated if training could improve cognitive control in individuals with sub-clinical levels of depression. Adaptive training and non-adaptive control groups underwent the intervention for eight days over a two week period. The adaptive training group's performance could increase in difficulty up to 4-back level while the non-adaptive control group only practiced the 1-back version of the task, without adaptation as a function of performance improvement. Training-related gains were found to transfer to behavioral and neural measures of working memory capacity and the efficiency of filtering of irrelevant information in the adaptive training compared to the control group. Other recent findings have also shown benefits of cognitive training in improvements on cognitive control. For example, Siegle, Price, Jones, Ghinassi, Painter and Thase (2014) showed that cognitive control training can have beneficial effects on reducing rumination in clinically depressed patients. Furthermore, Cohen, Mor and Henik (2015) showed training related gains on state rumination using a cognitive control training task that emphasized distractor interference. Finally, a study by Bomyea and Amir (2011) demonstrated that cognitive control training led to decreased intrusive thoughts, a hallmark of affective disorders including anxiety disorders.

The Current Study

Most studies performed so far have examined the beneficial effects of cognitive control training in the context of depression. Provided the relevance of impaired attentional control in anxiety (cf. Eysenck et al., 2007), the current study sought to determine if daily training for 15 days distributed over a three weeks period on the adaptive dual n-back task can result in improved attentional control in preselected high anxious individuals low on different measures of attentional control (Derryberry & Reed, 2002). We included a training group and an active control group. The training group performed an adaptive dual n-back task and the control group performed a non-adaptive dual 1 back task. To examine transfer of training, pre and post intervention measures of attentional control included: A Flanker task measuring distractor interference, an Antisaccade task with emotional faces as target to assess attentional control and inhibition in relation to emotional material, and resting state EEG (Theta/Beta) ratio, an index of prefrontal cortex related attentional control (Putman, Verkuil, Elsa Arias-Garcia, Pantazi, & van Schie, 2014). We now describe the selection of this transfer in more detail.

The Flanker task (Eriksen & Eriksen, 1974) was based on a modified version used in Berggren and Derakshan (2013). In this task, two types of arrows (distracter arrow, target arrow) indicating right or left were presented. Participants were instructed to ignore the distracter arrows and indicate the direction of the target arrow. The Flanker task has been used extensively in the literature in studies where distractor interference has been investigated (Shipstead, Harrison, & Engle, 2012; Lavie, Hirst, de Fockert, & Viding, 2004). Since high working memory capacity has been found to eliminate the adverse effect of acute stress (Otto et al., 2013), the Flanker task also included a state anxiety manipulation of presenting loud bursts of white noise randomly in half of the blocks. State anxiety manipulations using white noise have previously found to be successful (see Rossi & Pourtois, 2014). Using this manipulation, we aimed to assess selective attention under challenging conditions where the need to address the task demands is considered to place greater challenges on working memory functions for high anxious individuals (see Derakshan & Eysenck, 1997; Berggren, Richards, Taylor, & Derakshan, 2013).

The Antisaccade task (Hallet, 1978) was based on Derakshan, Ansari, Hansard, Shoker and Eysenck (2009; Exp 2). This task is a well validated and extensively used measure of attentional control in normal (see Hutton & Ettinger, 2006; Ettinger, Ffytche, Kumari, Kathmann, Reuter, Zelaya et al., 2008) and emotionally vulnerable populations suffering from anxiety and depression (see Berrgren & Derakshan, 2013, for a review). During the Antisaccade task, participants are required to saccade towards (prosaccade) or away from (antisaccade) an abrupt peripheral target flashed on the screen, as quickly as possible. Anxiety has been associated with a slowing on antisaccade latencies requiring the efficient exercise of attentional control processes of working memory in relation to target inhibition (e.g., Ansari & Derakshan, 2010; 2011a, Derakshan et al., 2009; Exp 1), and when the targets were angry facial expressions of emotion (Derakshan et al., 2009; Exp 2). Here, we used angry and neutral facial expressions as targets and were interested to observe training related gains on antisaccade latencies in relation to the inhibition of angry targets, predicting that training would result in faster antisaccade latencies especially for to-be-inhibited angry targets.

As a neurophysiological measure during the antisaccade trial, keeping with Ansari and Derakshan (2011a), we used Event Related brain Potentials (ERPs) focusing on the time window 50 ms prior to target presentation to observe if training affected changes in ERP activity in this interval which is known to predict antisaccade performance (Everling, Matthews, & Flohr, 2001). Ansari and Derakshan (2011a) previously found impaired performance efficiency during this interval as indexed by lower fronto-central negativity in high compared with low-anxious participants. Hence, given the sensitivity and reliability of this period in explaining antisaccade performance, we focused our analysis on this specific interval.

Resting state electroencephalography (EEG) as an alternative electrophysiological measure of trait attentional control was used. Via resting state EEG, we quantified neural activity in different frequency bands (i.e. theta band, 4-7 hz for slow oscillations; beta band, 13-30 hz for fast oscillations). Changes in power in these different frequency bands have been taken as an index of increased or decreased attentional control. For example, slow wave oscillation is mostly involved in stimulus driven processes whereas fast wave oscillation is related more to top down regulation of control and attention (Knyazev, 2007). Hence, an increased ratio between these two frequency bands was taken to indicate decreased cognitive or attentional control. For example, increased slow wave/fast wave ratio (SW/FW; theta/beta) is related to attentional problems such as Attention-Deficit/Hyperactivity Disorder (ADHD; Clarke, Barry, McCarthy, & Selikowitz, 2001; Arns, Conners, & Kraemer, 2012; but see Buyck & Wiersema, 2014b). Furthermore, Buyck and Wiersema (2014a) showed that specifically the inattentive subtype of ADHDwas related to abnormal SW/FW over the life span. Additionally, SW/FW negatively correlates with self-reported attentional control (Putman, van Peer, Maimari, & van der Werff, 2010; Putman et al., 2014) confirming that the SW/FW index can be used as a valid neurophysiological marker or correlate of attentional control.

Predictions

We predicted that participants in the adaptive training group would show improvement in working memory performance throughout the training period. Secondly, we predicted that such training related gains would transfer to attentional control processes at the neurophysiological level, as measured by the SW/FW, as well as performance on the Flanker task as a behavioral measure of distractor inhibition and the Antisaccade task as a measure of inhibition both at behavioral and neurophysiological levels. Lastly, due to the close links between WM and attentional control (Shipstead et al, 2014) extensive WM training was expected to lead to improvements in attentional control and eventually reduction in trait anxiety levels.

METHOD

Participants

Participants were student volunteers recruited via advertisements from the campus of Birkbeck University, London. They were pre-selected on the basis of their elevated trait anxiety scores on the trait anxiety scale of the State-Trait Anxiety Inventory (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983; STAI-TA ≥ 50) and low scores on the Derryberry and Reed's (2002) attentional control scale (ACS ≤ 60). Derryberry and Reed (2002) showed that such individuals are most strongly biased to process negative information. Participants were semi-randomly (the task started randomly either with the eyes open or closed condition and continued alternately) assigned either to the control (dual 1-back training: N = 16) or training (dual n-back training: N = 17) group. The training and control groups did not differ from each other on either STAI-TA (Control, M = 57.81, SD = 5.52; Training, M = 60.18, SD = 8.43; t < 1, *NS*) or ACS scores (Control, M = 45.88, SD = 8.15; for Training, M = 43.65, SD = 7.18; t < 1, *NS*) at baseline. The two groups had similar age (Control, M =26, SD = 5; Training, M =25, SD = 6; t < 1, *NS*) and gender distribution (Control, 2 males-14 females; Training, 6 males-11 females; χ^2 (1, N = 33) = 2.33, p = .13). Seven participants did not complete the study during the training without providing a reason (3 from control and 4 from training group). Participants were compensated 50 GBP, or given course credit for their participation.

Among the participants who completed the study, training and control groups also did not differ from each other either on STAI-TA scores (Control, *M* = 57.92, *SD* = 5.53; Training, *M* = 60.92, *SD* = 8.68; $t(24) = 1.05$, $p = .30$), ACS scores (Control, *M* = 45.85, *SD* = 8.99; Training, *M* = 43.08, *SD* = 6.95; $t < 1$, *NS*) at baseline, age (Control, *M* = 26, *SD* = 5; Training, *M* = 23, *SD* = 5; $t(24) = 1.51$, $p = .39$) or gender (Control, 1 males - 12 females; Training, 5 males - 8 females; $c^2(1, N = 26) = 3.47$, $p = .06$). At pre-intervention, training and control groups did not differ from each other on STAI-SA scores either (Training group, M = 47.62, SD = 10.17; Control group, M = 51.69, SD = 9.27, $t < 1$, *NS*).

Materials and Tasks

Self-report scales. Participants completed the State-Trait Anxiety Inventory (STAI-TA, STAI-SA; Spielberger et al., 1983), the Attentional Control Scale (ACS; Derryberry & Reed, 2002), and the Penn State Worry Questionnaire (PSWQ; Meyer, Miller, Metzger, & Borkovec, 1990) at pre and post intervention in the lab. The STAI-TA, STAI-SA and ACS each contain 20 questions and are presented on a 4 point Likert type scale. PSWQ has 16 items and is presented on a 5 point Likert type scale. While the STAI-TA, ACS, PSWQ measure trait characteristics, the STAI-SA measures state characteristics. The main interest of the current study is on trait anxiety assessed via STAI-TA.

Resting State EEG. Resting state EEG was recorded during 8 one-minute long blocks of alternating eyes open or eyes closed conditions (cf. Putman, Arias-Garcia, Pantazi & van Schie, 2012). The task started either with eyes open or closed conditions and continued alternately. Starting block was randomly decided for each participant. Since brain activity during an open or closed eyes condition may differ, the mean activity between these conditions is recommended to be the most informative index (Barry, Clarke, Johnstone, Magee, & Rushby, 2007). Hence, power densities for the three frontal electrodes (F3, Fz, F4) were averaged across these two conditions. Slow wave oscillations were represented by theta, in the 4-7 Hz frequency band while fast wave oscillations were captured by beta, in the 13-30 Hz frequency band activity during this state. The ratio between frontal slow wave and fast wave (SW/FW) activity was calculated as an index of attentional control (see Putman et al. 2010, 2014), with higher scores indicating lower attentional control levels.

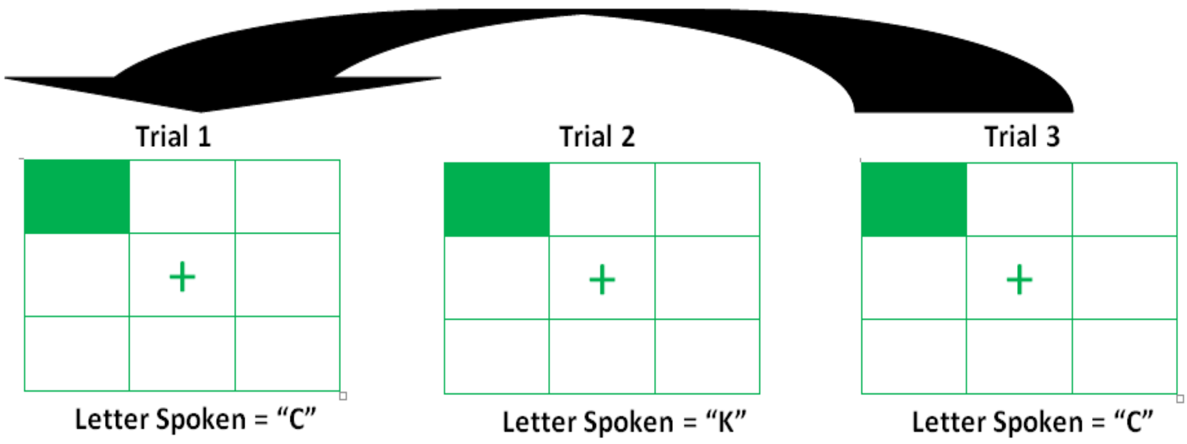
Flanker task. This task was a modification of the Flanker task used in Berggren & Derakshan (2013). Each trial started with a fixation cross for 500 ms. The distractor cues which were 2 sets of 2 arrows (<< or >>) appeared 3.1° above and below from fixation, pointing right or left (for a random duration between 12 to 26 ms depending on the monitor refresh rate -75 Hz. 98% of the time, duration was either 13 or 14 ms). Afterwards, a target arrow, which was a single set of 2 arrows pointing right or left, appeared in the middle of the screen. Participants were instructed to ignore the distracting cues and indicate the direction of the target arrow. In half of the trials, both target and distractor cue arrows showed the same direction (compatible) and in the other half they showed opposite directions (incompatible). Upon starting the task, the participants were informed they might hear a loud white noise (103 dbA) during the task. In half of the blocks, the white noise (perceived as aversive) was randomly presented during the inter trial interval (noise blocks) and there was no noise in the other half of blocks (safe blocks). Participants were informed whether they would hear a white noise at the beginning of each block. On noise blocks the noise was presented on ~10% of the trials. There were 4 blocks in total, each including 72 trials. Starting block was randomly determined. Participants in the training and control group did not differ from each other in terms of the condition of the block they started with, χ^2 (1, N = 33) = 1.59, p = .30.

Antisaccade task. This task was based on Ansari and Derakshan (2011b) with angry and neutral facial expressions (Lundqvist, Flykt, & Öhman, 1998) serving as target. There were 16 experimental blocks (8 antisaccade and 8 prosaccade) each containing 40 trials. These two facial expressions were distributed evenly within blocks. After a short practice session, the experimental blocks started either with an antisaccade or a prosaccade block, and continued alternately. Each trial started with a fixation cross for a variable duration ranging from 2600 to 3600 ms, and participants were instructed to fixate the cross whenever on the screen. Shortly after the fixation cross disappeared (200 ms gap), a face (3.3° × 6°) appeared 11° away from the center of the screen either at the right or left side along the horizontal axis.

After a short practice session, the experimental blocks started either with an antisaccade or a prosaccade block, and continued alternately. On prosaccade blocks, participants were instructed to look at the face and on antisaccade blocks, they were instructed to look away from the face to its mirror position on the screen as fast as possible without looking at it. Faces were presented for 600ms.

Adaptive Dual *n*- back Training Task. This online training task was similar to Owens et al. (2013) and based on the work of Jaeggi, Buschkuehl, Jonides, and Perrig (2008). Participants were presented a 3 by 3 grid with a fixation cross in the central cell (see Figure 1). A green square appeared in one of the remaining 8 cells. Five-hundred ms after the appearance of the square, a letter (c, h, k, l, q, r, s, or t) was spoken. Participants were asked to remember the position of the square and the letter spoken. If there was a match between the *n* trials back and the current one, they were asked to respond. If there was a position match, they pressed the “A” key on the keyboard. If there was a sound match, they pressed the “L” key. If both were matching, they were asked to press both keys. In case of no match, participants were instructed not to press any key. Each training session consisted of 20 blocks with 20 + *n* trial in each (for example, in a 2-back block there were 20+2=22 trials; in a 3 back block there were 20+3=23 trials). In each of the blocks, there were equal numbers of matches (4 for the position, 4 for the letter, 2 for both). Positions and the letter spoken were randomly distributed within the task. There were 15 seconds fixed breaks between blocks and participants could not terminate the task once it started. Each session lasted approximately 30 minutes. Level of task difficulty (*n*) increased depending on performance such that if accuracy on both the position and letter match was 95% or above, level of *n* increased by 1 in the following block. However, if accuracy rate was between 75% - 95%, participants continued with the same level. If their performance got worse (less than 75% accuracy), task difficulty decreased by one level of *n*. Participants were informed about the difficulty of the level in the beginning of each block.

Figure 1. The flow of n-back task. An example of a 2-back trial.



Non-adaptive dual 1-back control task. The control group completed 20 blocks of dual 1-back trials across the training days regardless of their performance. Here, participants were asked to respond if there was either a position, letter (or both) match with the previous trial.

Accuracy rate per training block for each participant was recorded online and immediately visible to the experimenter, as performance of participants was routinely monitored remotely by the experimenter. If accuracy rates were lower than regular, the participant was contacted in due time by the experimenter. No noticeable difference between the participants in the control group and the training group were observed on adherence to the instructions on the time of training during this period.

Procedure

Prescreened participants were invited to the lab where they completed the STAI-TA, ACS and PSWQ. They were then prepared for EEG testing and resting state EEG was recorded. Participants then performed the Antisaccade task. Afterwards EEG equipment was removed and the experiment continued with the Flanker task (due to the concerns about the length of the experiment session, EEG was not recorded during the Flanker task). Participants completed the STAI-SA before and after the task for assessments of state anxiety before and after the stress manipulation via white noise.

Finally, participants were given an introduction to the training task and were able to practice a few trials with the experimenter in the lab for familiarization with the task and to ensure that they had understood the instructions correctly. They were told that they should complete the task for 3 weeks at approximately the same time every week-day. Participants were able to see a summary of their daily performance and progress after each session. Additionally, they were told that the experimenter would be tracking their performance and completion rates on a daily basis. After the 3-week period, participants were invited back to the lab again for post-intervention measurements where they completed the same tasks and questionnaires as at pre-intervention.

EEG Data Acquisition

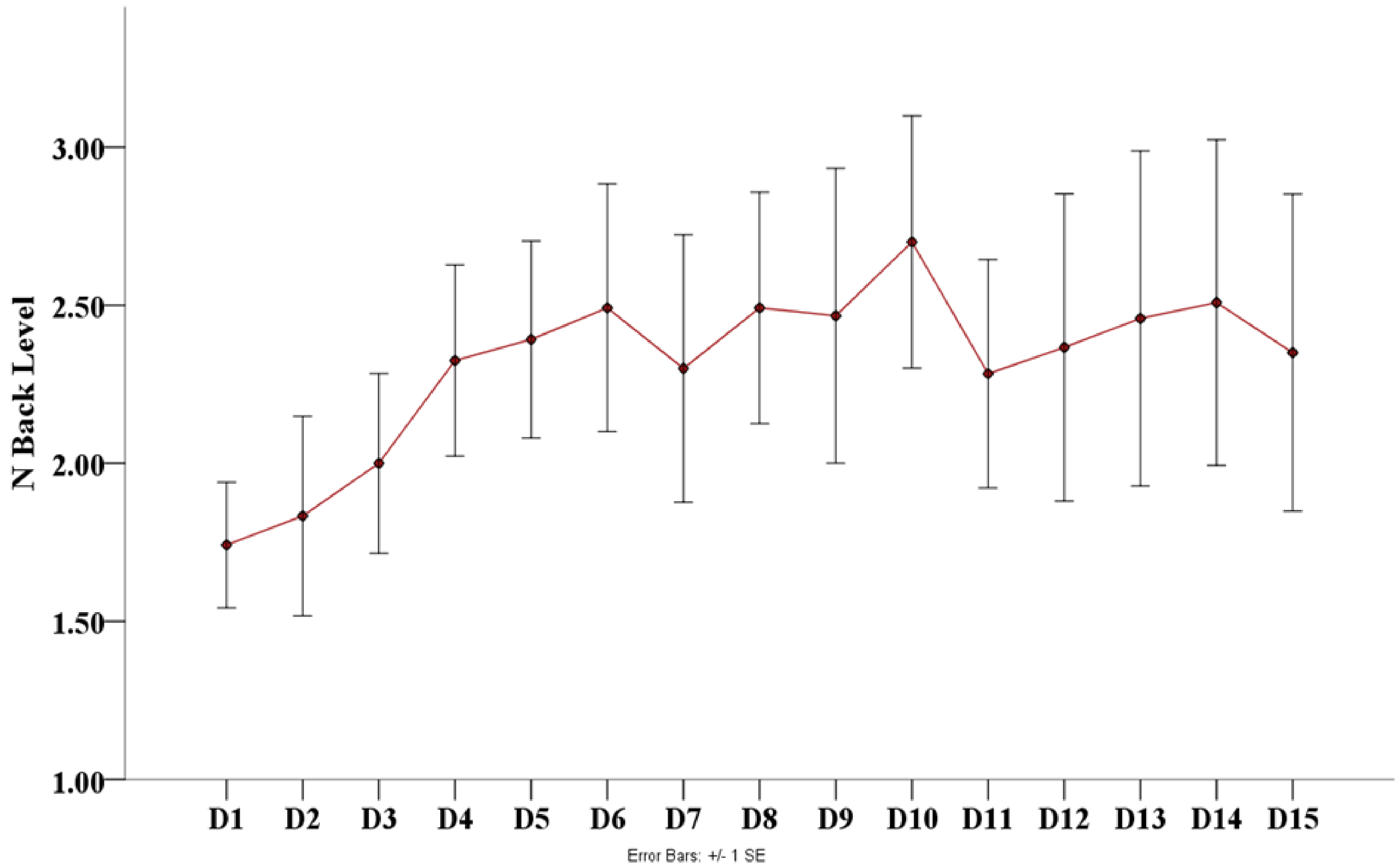
EEG data was recorded from 30 Ag/AgCl electrodes mounted in fitted cap (EASYCAP) according to 10/20 system (F3, Fz, F4, FC1, FC2, FC5, FC6, C3, Cz, C4, CP5, CP6, P3, Pz, P4). Electrode impedances were kept below 5kΩ. All electrodes were referenced on-line to the mean of left and right mastoids. Forehead was used as ground. Horizontal eye movements (HEOG) were recorded with electrodes placed on the outer canthi of the eyes and vertical eye movements (VEOG) were recorded from an electrode placed below the left eye. Data was amplified between 0.1 and 125 Hz, sampled at 1000 Hz and offline filtered with a bandpass frequency of 0.01-30 Hz for the Antisaccade task and 0.01-100 Hz for the resting state EEG. Data was automatically corrected for eye blinks and ocular artifacts. For the Antisaccade task, baseline correction was performed before and after ocular correction based on the pre-stimulus onset (300 ms). Artifact rejection criteria were set to ±90µV for the antisaccade task and ±100µV for the resting state EEG. After applying these criteria, at pre-intervention 79% and at post-intervention 83% of the resting state EEG data remained. For the antisaccade task, 12% of the data at pre-intervention and 6% of the data at post-intervention were removed due to artefacts.

RESULTS

Performance on the Training and Control Dual n-back Tasks

Figure 2 shows performance improvement on the dual n-back task in the training group. Working memory performance improved as indicated by greater levels of difficulty attained towards the end of training from mean performance in the first three days of training (M = 1.85, SD = .58) to the last three days (M = 2.49, SD = 1.10), $t(12) = 3.57$, $p < .01$. By comparison, the control group showed 94% accuracy overall and their scores did not vary from the first *n*-back session (95%) to the last *n*-back session (95%).

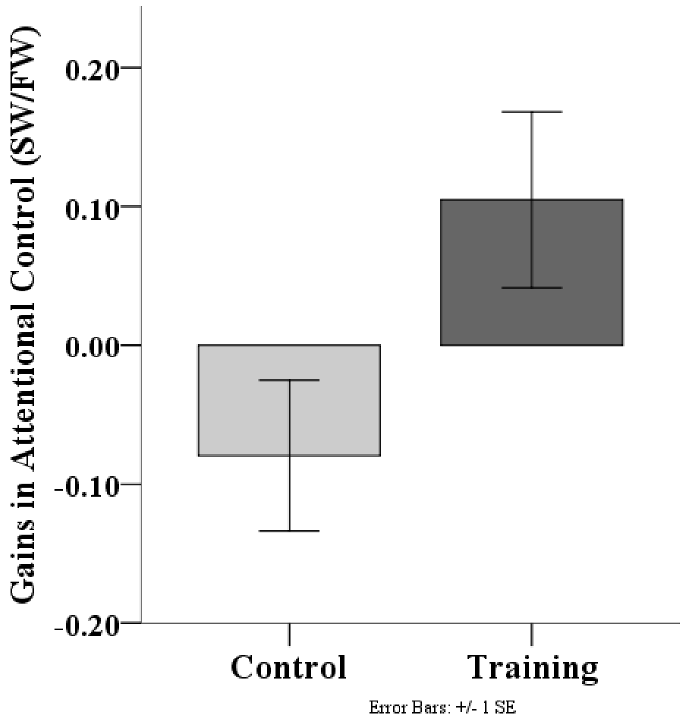
Figure 2. Performance of the training group over time on dual n back task.



Resting State EEG

Figure 3 shows the SW/FW EEG index for control and training groups at pre and post interventions, respectively. Data for 2 participants (1 from control, 1 from training) were lost during recording. Data were analyzed using a Mixed ANOVA with Time (pre-intervention, post-intervention) as within subjects factor and Group (Training, Control) as between subjects factor. There was no main effect of time, $F < 1$, but an interaction between Time and Group emerged, $F(1,22) = 4.90$, $p < .05$, that showed reductions in SW/FW from pre to post intervention in the training group ($M = .11$, $SD = .22$) that were greater than the changes observed in the control group ($M = -.08$, $SD = .19$), $t(22) = 2.21$, $p < .05$ who in fact even showed an increase in SW/FW. There were no group differences at pre- or post- intervention, both $ts<1$.

Figure 3. Gains in attentional control (reductions in SW/FW ratio) for control and training group separately.



Flanker task

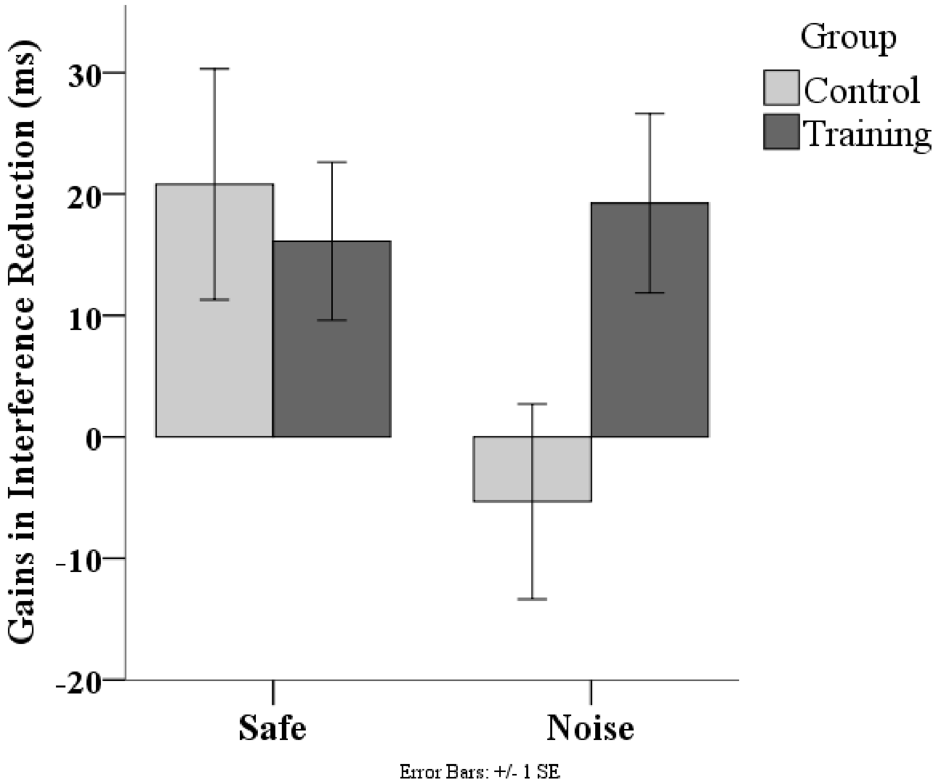
Data for 3 participants in the control group were discarded due to low accuracy rate (greater than 2.5 *SD* of the mean), slow reaction time (RTs slower than 2.5 *SD*) and extreme stress due to loud bursts. Only RTs for correct trials were considered. RTs exceeding 3 *SD* of the individual mean scores were also discarded. The analyses were run on 92% of the total pre-intervention and 93% of the post-intervention data.

Consistent with Berggren and Derakshan (2013), we calculated interference scores by subtracting RTs on compatible trials from RTs on incompatible trials. Interference scores were subjected to a Time (pre, post intervention) X Group (Control, Training) X Condition (Safe, Noise) Mixed ANOVA. A main effect of time, $F(1,21) = 6.89$, $p < .05$ showed that interference scores were lower at post ($M = 74$, $SD = 30$) compared with pre-intervention ($M = 87$, $SD = 36$). There was a main effect of condition, $F(1,21) = 5.00$, $p < .05$, with greater interference scores for noise ($M = 84$, $SD = 35$) than safe blocks ($M = 77$, $SD = 29$), which was qualified by a time X condition interaction, $F(1,21) = 4.60$, $p < .05$, indicative of greater reductions in interference in the safe (86 vs 68, $t = 3.34$, $p < .01$) compared with the noise condition, (88 vs 79, $t = 1.45$, $p = .16$). This observation was corroborated by a three way interaction of time X condition X group, $F(1, 21) = 7.46$, $p < .05$, where the training group showed significant reductions in interference in both safe and noise conditions from pre to post-intervention (both *t*s > 2.48, *p*s < .05), whereas the control group only showed a marginally significant reduction in the safe block ($t = 2.18$, $p = .056$) but not in the noise block ($t < 1$, *NS*; see Figure 4) [2].

[2] There was a marginal group difference at pre-test for the control group for the noise block, $t(21) = 1.74$, $p = .10$, but for the safe block, $t(21) = 1.26$, $p = .22$. There was no group difference at the post-test for the noise block, $t < 1$, *NS* and a marginal difference for the safe block, $t(21) = 1.77$, $p = .09$.

In order to assess state anxiety level during the Flanker task we averaged STAI-SA scores before and after the Flanker task. Time (pre, post intervention) X Group (Control, Training) mixed ANOVA led to significant main effect of time indicating lower scores at post-intervention (*M* = 48.24, *SD* = 7.67) as compared to pre-intervention (*M* = 50.85, *SD* = 9.11), $F(1, 21) = 6.86$, $p < .05$ but no interaction effect emerged $F(1, 21) = 2.29$, $p = .15$.

Figure 4. Gains in interference reduction for Flanker task for noise and safe blocks in control and training groups.



Antisaccade task

One participant's data was discarded due to the small percentage of accurate trials (2.5 *SD* lower than the mean). Analyses were run on correct saccades which were defined as the first saccade in the right direction after target onset (86% of trials at pre-intervention and 90% of trials at post intervention). Groups did not differ from each other either at pre or at post intervention in terms of correct saccades (all *t*s < 1, *NS*). In keeping with Ansari and Derakshan (2011b), saccades faster than 80 ms and slower than 500 ms were removed. Using Brain Vision Analyzer, leftward and rightward saccades were separated and the difference between the potentials of the left and right HEOG electrodes was calculated and saccades were identified as peaks. Peaks exceeding 50 µV on the correct/expected direction (polarity) were marked as valid saccades.

There were two main dependent variables: (i) Latencies of correct saccades, which were defined as the elapsed time between target onset and a saccade (i.e., peak in the HEOG) in the right direction, and (ii) central negativity, which was measured in the interval of 50 ms prior to target presentation, in line with Ansari and Derakshan (2011a) and Everling et al. (2001). Here, for central negativity, we averaged the activity of the electrodes at the central sites available (C3, Cz, C4)[3].

Latencies. Group comparisons for the antisaccade latencies at pre-intervention was marginally significant for neutral trials (Control, M = 269, SD = 37; Training, M = 244, SD = 25), $t(23) = 2.00$, $p = .058$ and significant for the angry trials (Control, M = 268, SD = 32; Training, M = 243, SD = 26), $t(23) = 2.15$, $p < .05$, indicating slower reaction times for the control group as compared to the training group. Hence, analyses on the post-intervention antisaccade latencies were run separately for each emotional condition controlling for the baseline differences. ANCOVA with antisaccade latencies as a dependent variable, group (control, training) as a fixed factor and pre-intervention antisaccade latencies as a covariate revealed no group differences for either of the conditions (neutral faces: control, M = 253, SD = 31; training, M = 221, SD = 31, $F(1, 22) = 2.05$, $p = .17$; angry faces: control, M = 252, SD = 28; training, M = 221, SD = 29, $F(1, 22) = 2.32$, $p = .14$).

[3] In keeping with Ansari and Derakshan (2011a) and Everling et al. (2001), we also looked at the frontal negativity (averaged F3, F4, Fz). However, due to technical problems these channels were considerably noisy as compared to central ones and did not lead to any significant group X time X valence interactions, $F < 1$, *NS* (for antisaccade); $F(1, 23) = 1.06$, $p = .31$ (for prosaccade).

For the prosaccade latencies, a Mixed ANOVA with Time (pre-intervention, post-intervention) and valence (neutral, angry) as within subjects factors and Group (Training, Control) as between subjects factor was run. There was a marginal valence x group interaction; $F(1, 23) = 4.24$, $p = .051$, indicating that the control group was slower on angry ($M = 176$, $SD = 15$) vs neutral trials ($M = 175$, $SD = 15$), as opposed to the training group who showed slower latencies on neutral ($M = 167$, $SD = 13$) compared to angry trials ($M = 165$, $SD = 12$). No other effect reached significance (Time x Group interaction, $F(1,23) = 2.19$, $p = .153$, all the other *F*s < 1, *NS*.).

Figure 5a. Central Negativity for pre to post-intervention (positive value indicates increased negativity) for the control group for neutral and angry trials. Negative is plotted down. Waveforms were filtered with a high cutoff filter of 5 Hz (slope 24 dB/oct) for visual inspection.

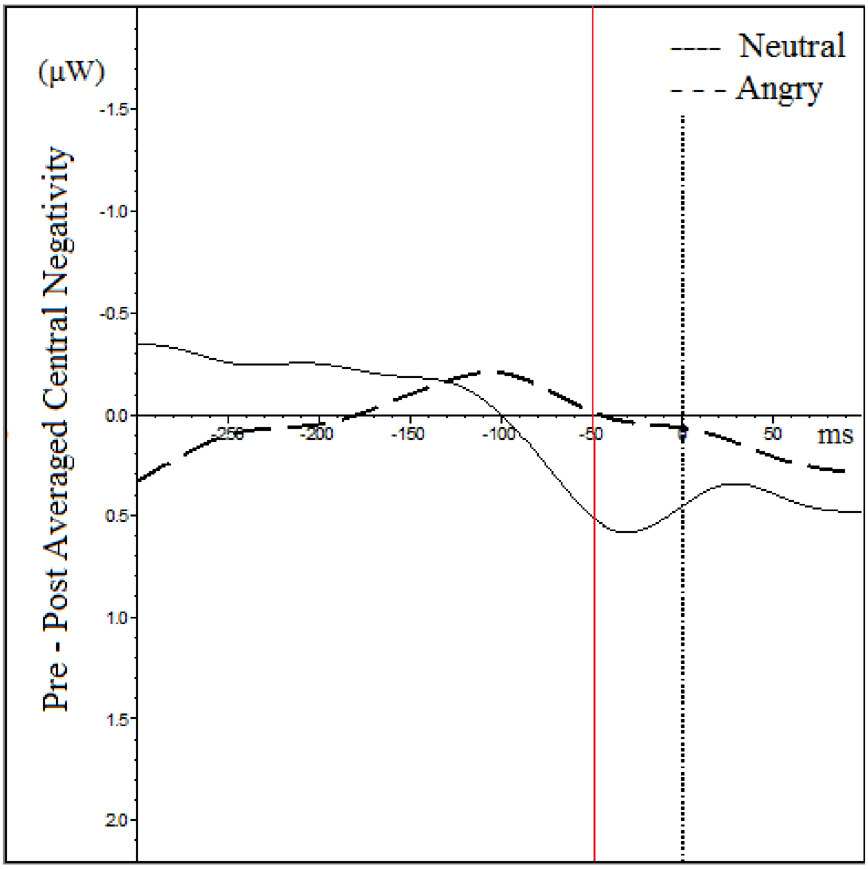
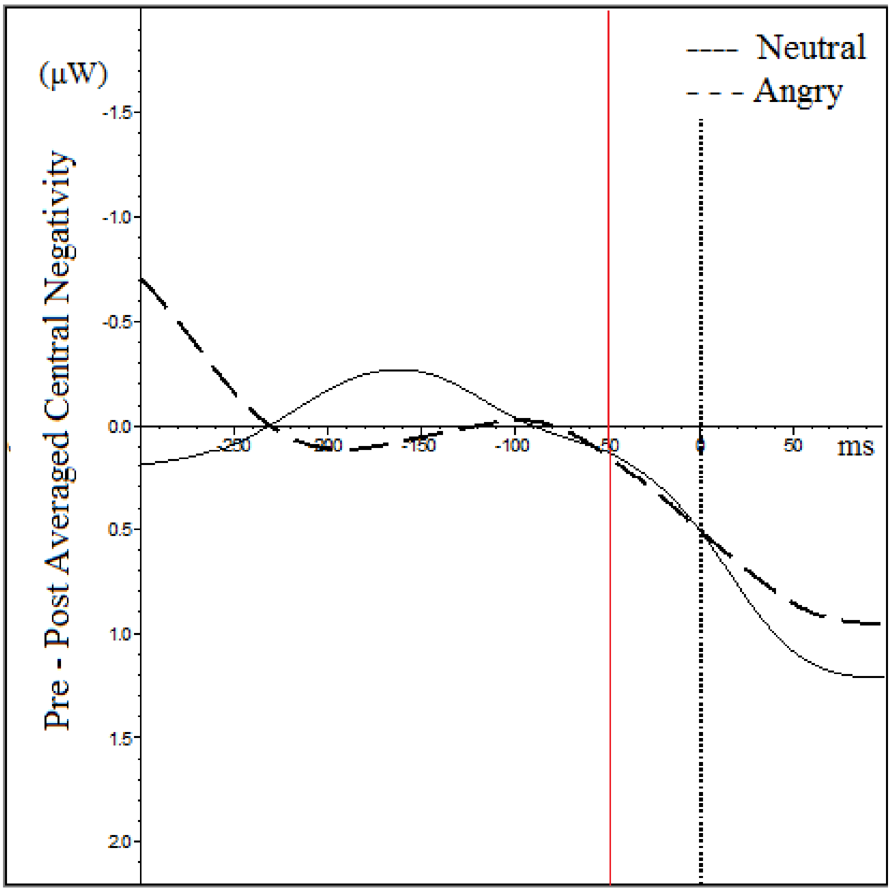


Figure 5b. Central Negativity for pre to post-intervention (positive value indicates increased negativity) for the training group for neutral and angry trials. Negative is plotted down. Waveforms were filtered with a high cutoff filter of 5 Hz (slope 24 dB/oct) for visual inspection.



Central Negativity. Figure 5 shows the grand averaged waveforms for antisaccade trials pre to post intervention difference, for neutral and angry trials. A mixed ANOVA with Time (pre – post intervention) X Valence (angry, neutral) X Group (training, control) showed a significant main effect of Time, $F(1,23) = 10.80$, $p < .01$, indicative of a greater negativity at post intervention ($M = -1.19$, $SD = 1.03$) vs pre-intervention ($M = -0.88$, $SD = .89$). A trend effect of valence, $F(1,23) = 3.23$, $p = .09$, indicated greater negativity for angry ($M = -1.14$, $SD = .92$) vs neutral ($M = -.93$, $SD = 1.03$), and a marginal interaction between valence x time, $F(1, 23) = 2.98$, $p = .10$, with a greater increase in negativity for neutral faces (-.7 vs -1.16) vs angry faces (-1.06 vs -1.23) were found. The three way interaction of time X valence X group, $F(1, 23) =$

5.43, $p < .05$, revealed that the control group had greater increase in negativity (*M*diff = -0.78; $t = 3.77$, $p < .01$) on neutral trials, and no increase on angry trials, $t < 1$. The training group on the other hand showed a marginal increase on angry trials (*M*diff = -.24; $t = 1.85$, $p = .08$, two tailed), and no increase on neutral trials, $t < 1$.

Self-reported Symptomatology

Separate mixed ANOVAs for each scale (ACS, PSWQ, STAI-TA) with time (pre-intervention, post-intervention) as within subjects factor and group (training, control) as between subjects factor revealed no significant main effect of time for ACS, $F(1, 24) = 2.41$, $p = .13$; PSWQ, $F < 1$, *NS*; STAI-TA, $F(1, 24) = 1.56$, $p = .22$. Furthermore, no group X time interactions were observed for any of these scales ($F < 1$, *NS* for all scales). There were no group differences for ACS, PSWQ and STAI either at the pre-intervention or at the post-intervention (all *ts* < 1, *NS,* see Table 1 for descriptive statistics.). Separate paired t-tests for each group revealed no significant difference pre to post intervention for the control group in any of these scales either (PSWQ, ACS, $t < 1$, *NS*; STAI-TA, $t(12) = 1.12$, $p = 29$). The training group also did not show any significant improvement on scores on the PSWQ and STAI (*ts* < 1, *NS*), but there was a significant trend for an increase in attentional control post vs pre intervention, $t(12) = 1.89$, $p = .08$.

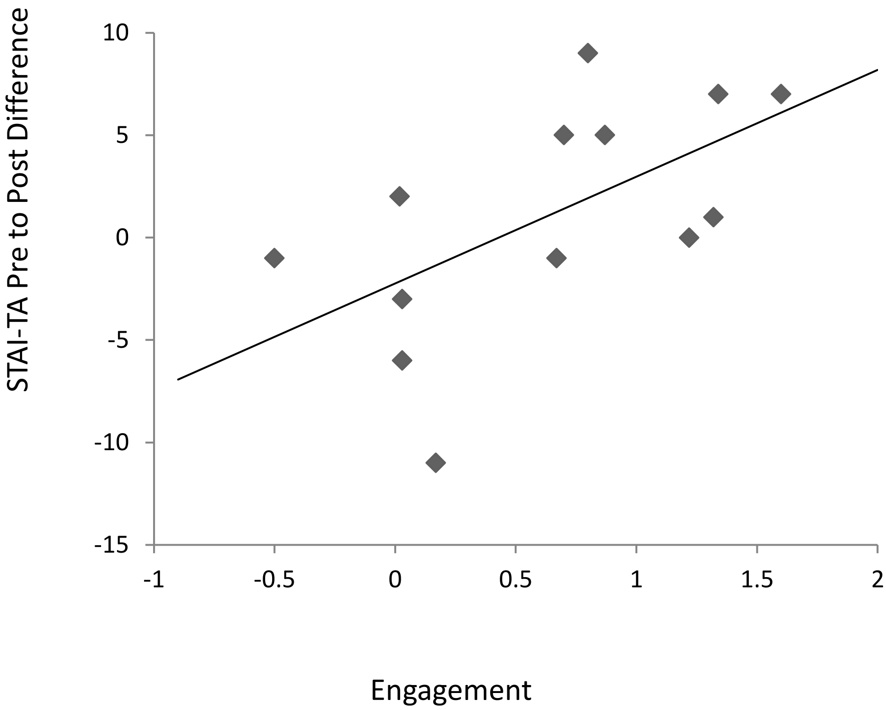
Table 1. Mean self-reported symptomatology at pre- and post-intervention for control and training group separately (SDs are presented in parentheses).

	Pre-intervention		Post-intervention	
	Control	Training	Control	Training
ACS	45 (12)	44 (8)	46 (10)	45 (9)
PSWQ	64 (12)	66 (7)	62 (11)	65 (9)
STAI-TA	57 (8)	56 (9)	55 (9)	55 (9)

Training improvement and changes in self-reported trait anxiety

Following previous recommendations on the role of training engagement in reducing negative symptomatology (see Siegle et al., 2014), we also considered how engagement with and improvement on the training task was associated with changes in self-reported trait anxiety. Here, the level of training-related improvement (i.e., mean level of difficulty in the first three days of training to the last three days) was taken as an index of the level of engagement. Based on this index, we divided the training group into two (high-engaged group, $N = 7$, $M = 1.12$, $SD = 0.33$; low-engaged group, $N = 6$, $M = 0.07$, $SD = 0.37$) by a median split and conducted an ANOVA with change in trait anxiety (pre-intervention – post-intervention) as a dependent variable and engagement level as a between subjects factor. There was a significant effect of task engagement on change in trait anxiety, $F(1, 11) = 14.01$, $p < .01$. The high-engaged group showed a greater decrease (*Mdifference* = 4.86, $SD = 3.29$) in trait anxiety scores as compared to the low-engaged group (*Mdifference* = -3.33, $SD = 4.59$) who showed a slight increase in trait anxiety scores. In line with these results, we considered the full variation in level of engagement and trait anxiety and performed a correlational analysis between the level of engagement and change in self-reported trait anxiety (see Figure 6). Level of engagement with the training task was positively correlated with greater reductions in self-reported trait anxiety pre to post intervention in the training group, $r(13) = .59$, $p < .05$.

Figure 6. The relationship between training improvement/level of engagement (averaged performance on last 3 days – first 3 days) and reduction in trait anxiety scores.



DISCUSSION

The current study set out to examine whether extensive working memory training can improve attentional control processes in high trait anxious individuals. We used resting state EEG measures as an indirect neural index of trait attentional control, the flanker task as a behavioral measure of distractor interference with and without threat, and the antisaccade task with emotional faces as a measure of valence-specific inhibitory control. The causal roles of attentional control and working memory capacity as determinants of emotional vulnerability and resilience are becoming increasingly important in both theoretical models of anxiety and depression (see Berggren, & Derakshan, 2013; Waugh, & Koster, 2014) and in explaining exaggerated processing styles for negative information as well as clinical applications of such models in reducing ruminative styles of thinking (e.g., Cohen et al., 2015; Siegle et al., 2014).

Given recent theoretical debates on the usefulness of working memory training (e.g., Shipstead et al., 2012), it is of crucial importance to examine cognitive transfer of training-related gains onto untrained tasks using multiple outcome measures. In this proof-of-principle study, we examined whether adaptive training vs. an active control training resulted in improved attentional control on behavioral as well as neural levels in various transfer tasks. Moreover, we were interested to see if training could lead to reductions in self-reported anxious symptomatology. The main results are that working memory training resulted in improved attentional control at the behavioral level assessed via the Flanker task and neural level observed in terms of SW/FW. Furthermore, level of training-related improvement was associated with reductions in levels of trait anxiety. We discuss the implications of these findings below.

Training related gains at the behavioral level were examined via the Flanker task that included a stress-related manipulation in order to assess distractor interference and cognitive control under conditions of high anxiety and competing task demands. Moreover, we examined transfer to emotional information processing on the Antisaccade task that included angry and neutral facial expressions as targets. At post intervention participants in both training and control groups showed improvements on the Flanker task in terms of their ability to resist distracting interference when identifying targets with this effect being greater in flanker blocks where state anxiety was manipulated via bursts of white noise. Crucially, when exposed to unpredictable bursts of white noise, participants in the training group showed an improvement compared with baseline whereas those assigned to the control group showed no significant improvement but rather a cost under these conditions. These results suggest that working memory training helped enhance cognitive performance under stressful situations when the efficient exercise of attentional control was required to cope with the (likely) presentation of an external aversive stimulus and enforce focusing on the (Flanker) task at hand. This interpretation dovetails with the results of the study by Otto, Raio, Chiang, Phelps and Daw (2013) that showed that during a learning task participants high in working memory capacity did not suffer from the detrimental effects of stress as compared to the participants low in working memory capacity that did so.

Training-related gains seemed not to transfer to performance on the antisaccade task as assessed by antisaccade latencies and error rates. A closer examination of neural activity right before the onset of saccades during the 50 ms interval prior to target presentation showed no significant increase of central negativity for the training group, with the control group showing an increment only for neutral facial expressions during antisaccade trials. However, this increment on central negativity was not reflected on behavioral task performance. Hence, increased central negativity without any behavioral improvement may in fact reflect the inefficient use of cognitive resources towards achieving behavioral outcomes (see Ansari & Derakshan, 2011a,b) suggestive of the fact that in the absence of anxiety-related difference in terms of antisaccade latencies increased cognitive effort without any advantage on performance may reflect deficiencies in processing efficiency towards the desired behavioral outcome. Nevertheless, results with regard to antisaccade performance were not in the expected direction.

One plausible explanation for the lack of a significant transfer effect could be related to the use of emotional targets in the antisaccade task which may have necessitated some form of emotional working memory training or control (see Schweizer, Hampshire, & Dalgleish, 2011) facilitating the specific processes underlying selective attention to and inhibition of threat-related material. Accordingly, future studies should investigate the transfer of training related gains on an Antisaccade task that incorporates neutral shaped objects (e.g., oval shapes e.g., Derakshan, Saville & Course-Choi, in preparation) rather than emotional faces. It is worth mentioning that the working memory training transfer effects in Owens et al (2013) were also observed in relation to enhanced inhibitory control and the filtering of irrelevant information devoid of emotional content. Furthermore, the antisaccade task used in the current study followed a blocked design (separate blocks for antisaccade and prosaccade trials). Future research can examine training related effects on a more challenging version of a mixed antisaccade task where anti and prosaccade trials are mixed (Ansari, Derakshan, & Richards, 2008; Vanlessen, De Raedt, Mueller, Rossi, & Pourtois, in press).

Finally, working memory training resulted in transfer of gains to resting state EEG, as measured by SW/FW ratio. The ratio between the power density in SW and FW band frequencies has been previously related to trait attentional control (Putman et al., 2014). While increased SW/FW is related to attentional problems (Clarke et al., 2001; Arns et al., 2011), decreased SW/FW is related to better attentional control (Putman et al., 2012, 2014). In our study, we observed a reduced SW/FW for the training group only. Although improvement on a trait-like measure in a short time period (3 weeks) is remarkable, trait-like improvements like fluid intelligence (Au et al., 2014; Schweizer et al., 2011) or WM capacity (Schweizer et al., 2013; Owens et al., 2011) were observed as a function of WM training in many other studies as well. This finding is valuable as it may indicate that working memory training can yield improvements in attentional control mechanisms at the neurophysiological level.

Training Related Gains on Anxiety Vulnerability, and Clinical Implications

An interesting finding concerns the relationship between training-related improvements and changes in self-reported anxiety which was amongst our primary goals. Although we did not observe any group differences on anxiety scores at post-intervention, we found decreased anxiety scores for participants who improved the most on the training task. While high-engaged participants showed decreases in levels of trait anxiety, low-engaged participants showed the opposite pattern. The relationship between training improvement and decreased anxiety was also evident at a correlational level indicating that increased engagement was related to decreased anxiety scores. This finding is valuable as it may indicate that the higher engagement with the task, the greater processing efficiency and reductions in anxious symptomatology. From a motivational perspective, this finding extends previous claims that higher levels of motivation could predict greater engagement with the task, which might in turn be related to enhanced training related gains (Jaeggi, Buschkuehl, Shah, & Jonides, 2014). Furthermore, this finding resembles effects obtained in clinical depression (Siegle et al., 2014) where applied cognitive training in a depressed population undergoing psychotherapy and medication led to additional benefits in treatment outcome for participants who engaged with the task to a greater level. Due to the limitations considered with our small sample sizes in each group replication with a larger sample to examine the relationship between training related gains and anxiety would be highly desirable.

Conclusions, Limitations and Future Directions

In line with the ACT (Eysenck et al., 2007), we observed that improved levels of working memory performance was related to improved attentional control, especially when participants were required to perform the flanker task under stress, as well as to reductions in self-reported anxious symptomatology post relative to pre intervention, and resting state neurophysiological indices of attentional control. Such improvements were observed under conditions where anxiety elicited effects could be maximally observed (Berggren, Koster, & Derakshan, 2012; Berggren & Derakshan, 2013). It can be argued that working memory training led to increases in the regulation of top-down control mechanisms, thereby resulting in decreased interference from bottom-up influences in trait vulnerability to anxiety. Despite such improvements in performance and resting state EEG, the transfer effects on inhibitory control as assessed by the antisaccade task were less conclusive and future research should examine the possible transfer effects of adaptive cognitive training using the dual n-back on non-emotional versions of the antisaccade task (e.g., Derakshan et al., in preparation). While the current study elucidates the link between attentional control and anxiety within the ACT framework, and sheds some light on the mechanisms in working memory responsible for the effects of anxiety on performance, it opens up fruitful avenues for future work to explore further the exact processes that need targeting in training paradigms. Here, working memory was trained and training related gains on attentional control was assessed in a broad fashion. Currently, the state of the literature on training does not specify whether distinct components of attention are trained. If working memory training influences attentional control in a broad sense one would expect changes across a range of different attentional tasks. However, provided that training related transfer was not observed on every attention task in the current study this begs the question how each of the specific attentional processes (e.g., either inhibition, shifting or updating information) might be influenced as a function of working memory training. Moreover, whether these effects then generalize to other processes of working memory remains an open question (see Shipstead et al., 2012).

It will be beneficial for future studies to consider having follow-up sessions of testing to examine the stability of the obtained transfer effects. Although extensive working memory training studies are resource extensive, future research should have a greater number of participants in each group. Our sample sizes in the current investigation were small, which made it difficult to eliminate the effects of individual differences at group level and might be responsible for some of the baseline differences between the training and control group, for example on antisaccade latencies. Although, these differences were statistically controlled, with a greater sample size more solid conclusions can be reached.

In conclusion, this study contributes to our understanding of the causal relationship between attentional control mechanisms and anxiety. Our findings suggest that working memory training may have a beneficial contribution to improve attention or inhibition-control deficits typically associated with anxiety, and the vulnerability to develop anxiety disorders. The results of the current investigation pave the way for more extensive and multilevel investigations of how working memory training through its influence on attentional control may help protect against trait vulnerability to anxiety.

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CHAPTER 7

GENERAL DISCUSSION

RECAPITULATION OF THE RESEARCH GOALS

The main focus of this dissertation was on anxiety and cognitive vulnerability factors in anxiety. Anxiety refers to an unpleasant, apprehensive emotional state in response to perceived threat (Rachman, 1998). Although it essentially is an adaptive state in order to deal with dangerous/threatening situations, prolonged anxiety in the absence of an actual threat can be rather maladaptive; and this is typically the case with anxiety disorders (Eysenck, 1992; Barlow, 2002; Gray & McNaughton, 2003; Clark & Beck, 2011). Anxiety disorders are one of the most prevalent psychological disorders especially in western developed countries (global prevalence rate considering 6-month to 12-month estimates ranges from 2.4% to 29.8%; Baxter, Scott, Vos, Whiteford, 2013; see also Kessler, Chiu, Demler, & Walters, 2005). Prominent theories and models in anxiety emphasized the importance of cognitive risk factors of anxiety since these factors greatly contribute to the etiology and maintenance of anxiety disorders (Eysenck, 1992; Eysenck & Calvo, 1992; Beck & Clark, 1997; Williams, Watts, MacLeod & Mathews, 1988; Mogg & Bradley, 1998; Eysenck, Santos, Derakshan, & Calvo, 2007; Grupe & Nitschke, 2013). These theories proposed that anxiety is related to information processing biases with regard to threat-related stimuli (Beck & Clark, 1997; Williams et al., 1998; Mogg & Bradley, 1998; Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van Ijzendoorn, 2007); but also general impairments in core cognitive mechanisms such as working memory (WM) and attentional control (Eysenck, 1992; Eysenck et al., 2007; Berggren & Derakshan, 2013).

WM is a limited capacity cognitive system which is essential to perform complex tasks (Baddeley, 1992); and capacity of WM is explained in terms of one’s ability to process task-relevant information while resisting distracter interference (Shipstead, Harrison, & Engle, 2012). WM processes are also closely associated with attentional control (Baddeley, 2003; Gazzaley & Nobre, 2012; Shipstead, Lindsey, Marshall, & Engle, 2014). Hence, inefficient recruitment of attentional control can be related to inefficient functioning of WM as well. Efficient processing of attentional control is dependent on the complex interaction between two sub-systems of attention: a Bottom-up system (stimulus-driven and reflexive) and a Top-down one (goal-directed and volitional; Corbetta & Shulman, 2002; Theeuwes, 2010; Posner & Petersen, 1990).

Considering the importance of cognitive theoretical accounts of anxiety, in this dissertation, we systematically investigated anxiety-related information processing biases and impairments in attentional control and WM. More specifically, we examined bottom-up influences; such as, attentional bias to threat **(Chapter 2, 3, and 5);** and also general impairments in top-down attentional control and WM **(chapter 4, and 6).** Research goals within each chapter are briefly recapitulated below.

A wealth of research demonstrated a strong link between anxiety and attentional bias (see Bar-Haim et al., 2007 for a review). However, the influence of early attentional bias to threat on further stages of information processing in relation to trait anxiety has not been thoroughly examined. **Chapter 2** aimed to address this issue. In **chapter 2**, we investigated the role of trait anxiety on encoding (early processing) and maintenance (late processing) of threat-related stimuli and explored the possible interaction between these early and late processes. Since anxiety is mainly associated with impairments in processing efficiency rather than performance effectiveness (Eysenck & Calvo, 1992; Eysenck et al., 2007), in addition to behavioral indices, we included event related potentials (ERPs) in order to obtain a clearer picture of neural events (with a focus on their electrophysiological time-course in the present case) potentially giving rise to specific behavioral effects. Furthermore, the impact of cognitive (WM) load was also considered, because anxiety-related effects on performance are critically dependent on task demands and the amount of cognitive efforts that need to be invested in a given task (Eysenck et al., 2007; Berggren & Derakshan, 2013).

Chapter 3 also focused on anxiety related-effects on WM considering attentional bias and task load, yet in this chapter, we focused on examining the influence of state anxiety. Previous findings have shown that state anxiety was related to *impairments* in WM using emotionally neutral tasks (Lavric, Rippon, & Gray, 2003; Shackman, Sarinopoulos, Maxwell, Pizzagalli, Lavric, & Davidson, 2006; Vytal, Cornwell, Arkin, & Grillion, 2012; Vytall, Cornwell, Letkiewicz, Arkin, & Grillion, 2013); but also anxiety-related *benefits* in attentional control in the presence of threat-related stimuli in the environment (Lystad, Rokke and Stout, 2009; Birk, Dennis, Shin, & Urry, 2011). Hence, the effect of state-anxiety on WM in the presence of threat-related stimuli is still not entirely clear. In **chapter 3**, we attempted to investigate this issue. Both **chapters 2** and **3,** aimed to gain a better understanding of the effects of anxiety (at trait and state level) on WM in relation to attentional bias and (cognitive) task load.

In **chapters 4** and **5,** the focus was on the worry component of anxiety. Worry is referred to as a key "cognitive component" of anxiety and it is closely associated with impairments in attentional control and WM (Mathews, 1990; Eysenck & Calvo, 1992; Hirsch & Mathews, 2012). However, the direct relationship between worry and WM capacity has not been fully investigated yet. In **chapter 4,** by experimentally manipulating levels of worry, and obtaining WM capacity scores before and after the manipulation, we sought to examine whether worry induces a cognitive cost, depleting working memory resources.

In **chapter 5,** we investigated worry-related influences in processing of threat-related stimuli. Worry has been associated with threat-related biases in information processing (Hirsch & Mathews, 2012). By experimentally inducing worry, before performing a visual search task with threat-related (angry faces) stimuli, we aimed to observe direct influences of worrying on selective attention to threat. Furthermore, we also considered the effect of WM capacity on this relationship. WM capacity is associated with better attentional control and reduced interference by distractor (Barrett, Tugade, & Engle, 2004). Accordingly, high WM capacity can reduce the impact of worry on performance in the presence of threat-related distractors. Hence, **chapter 5** focused on the influence of worry on selective attention to threat and possible moderating role of WM capacity on this relationship. In essence, in **chapters 4** and **5**, we aimed to investigate the direct relationship between worry, WM, and also attentional bias to threat by manipulating levels of worry experimentally.

Lastly, in **chapter 6** the causal status of the relationship between anxiety and impairments in WM was investigated. For this purpose, a WM training (dual-n-back training; Jaeggi et al., 2003) was applied in a (sub clinical) high-trait-anxious sample. Participants were randomly assigned either to a training or an active control condition. In order to investigate training-related gains, participants performed several cognitive tasks assessing attentional control and WM; filled in questionnaires with regard to anxiety, attentional control, and worry before and after the training/active control procedure. In this study, in addition to training-related gains in attentional control and WM, the relationship between improvement in WM training task and self-reported anxious symptomatology was also explored systematically.

In the following sections, the main findings of the experimental research conducted in **chapters 2, 3, 4, 5 and 6** are reported; before their theoretical and practical implications are discussed. Furthermore, limitations and future directions are addressed. Finally, we end this section by formulating concluding remarks and general recommendations for future research in this area.

SUMMARY OF MAIN FINDINGS

In **chapter 2**, in order to investigate the influence of trait anxiety on processing threat-related information under varying WM (cognitive) load conditions, we used a standard face change detection task where emotion (neutral vs fearful faces) and WM load (high vs low load) were manipulated using a factorial design. At the behavioral level, we focused on accuracy rates, sensitivity scores (*d prime*), and WM capacity (*K scores*). In our ERP analyses, we focused on the N170 occipito-temporal component (as a marker for early face processing and encoding) and the contingent negative variation (CNV; for late information processing, maintaining, and anticipatory cognitive effort). The main findings were as follows: (1) at the behavioral level a clear effect of WM load was observed, yet, regardless of the actual emotional facial expression held in WM and levels of anxiety. As expected, participants had lower accuracy rates, lower sensitivity scores, and higher WM capacity scores under high compared to low WM load condition. (2) For the N170 ERP component, we observed an interaction effect between WM load and anxiety. This interaction indicated that higher levels of anxiety were related to a larger N170 amplitude under high compared to low WM load. (3) For the subsequent CNV activity, there was an interaction effect between WM load, emotion and anxiety indicating that higher levels of anxiety were related to a lower CNV activity under high compared to low WM load in the presence of fearful faces. (4) Lastly, we observed a trend suggesting an interplay between N170 and CNV activity. More specifically, difference in the amplitude of the N170 between high and low WM load was inversely related to the difference in the amplitude of the CNV activity between high and low WM load in the presence of fearful faces. Moreover, this relationship was more evident at higher levels of anxiety. The findings of this study suggest a possible connection between enhanced (early/perceptual) processing of fearful faces (indexed by N170 activity) and reduced (post-perceptual) processing efficiency of WM in response to task demands (indexed by CNV activity) in individuals with high trait anxiety.

In **chapter 3**, the influence of state anxiety on WM was investigated considering cognitive load and emotion. We used a WM task which combines two subsequent tasks: a number recognition task (where cognitive/WM load was manipulated); a one-back task with pictures (where emotionality was manipulated via threat-related vs neutral pictures). State-anxiety was manipulated via threat of shock before starting the task. In this investigation, we observed that state-anxiety was related to interference by threat-related stimuli during the number recognition task only under high cognitive load condition. More specifically, higher pre to post increments in the level of state anxiety were related to lower interference by threat under high cognitive load condition. Similar results were obtained in relation to state anxiety levels after the mood induction procedure. There was a negative relationship between state anxiety levels and interference scores under high cognitive load. The findings of this investigation suggest state anxiety-related performance benefits in WM in the presence of threat-related stimuli under high cognitive load.

In **chapter 4**, in order to examine the influence of active worrying on WM capacity, participants were assigned either to a worry condition where they were asked to focus on a personal worrisome concern or to a control condition where they were asked to focus on a personal positive topic (cf. Hayes, Hirsch, Mathews, 2008). WM capacity was assessed before and after the worry/control manipulation using a change detection task with neutral stimuli (Vogel, McCollough, & Machizawa, 2005). The results indicated that participants in the worry condition had greater reductions (or attenuated improvements) in WM capacity in relation to elevated worry. The findings of this study dovetail with the assumption that worry consumes limited attentional resources leading in turn to impairments in WM capacity.

In **chapter 5**, effects of worry on selective attention to threat were scrutinized considering the possible influence of WM capacity on this relationship. Similar to the procedure in **chapter 4**, participants first performed a change detection task with neutral shapes (Vogel et al., 2005) to assess WM capacity. Next, they were assigned to a worry or control condition where worry/control manipulation took place (cf. Hayes et al., 2008). Afterwards, participants performed a visual search task (i.e. Öhman, Flykt, & Esteves, 2001) with happy, neutral or angry faces. The results showed that condition (worry vs control) did not influence visual search task performance under any of the task conditions. Furthermore, the relationship between condition (worry vs control) and visual search task performance did not emerge in any level of the WM capacity either.

In **chapter 6,** we applied WM training in an (subclinical) anxious sample. Participants were assigned either to training or active control condition. Before and after the training/control interventions, we measured resting state EEG where slow wave/fast wave ratio (SW/FW; cf. Putman, Verkuil, Elsa Arias-Garcia, Pantazi, & van Schie, 2014); a modified version of Flanker task (Eriksen & Eriksen, 1974) with stress (presentation of random loud bursts) and safe (regular Flanker task) conditions; and an Antisaccade task (Hallet, 1978) with emotional (angry vs neutral) faces. During the anti-saccade task, in addition to saccade latencies, we also focused on ERPs (central negativity) prior to target presentation. At pre-post intervention sessions, participants also filled in questionnaires with regard to anxiety, worry, and attentional control. Main findings were as follows: (1) Training-related gains were observed in resting state EEG; participants in the training condition had reduced SW/FW (lower SW/FW is usually associated with better attentional control; Putman et al., 2014) at pre to post intervention. (2) Participants in both training and control conditions showed improvements on the Flanker task in the safe condition. However, only participants in the training condition showed improvements in the stress condition. (3) Training-related gains were not observed either in saccade latencies or central negativity during the Antisaccade task. (4) Participants in the training condition had reduced self-reported trait anxiety in relation to improvements in the training task. These results lend support to the notion of training-related gains in attentional control and WM in emotionally-natural tasks and also self-reported anxious symptomatology.

THEORETICAL AND PRACTICAL IMPLICATIONS

Our results have important theoretical and practical implications with regard to anxiety-related information processing biases and impairments in WM and attentional control. These implications are presented considering the effects of anxiety on top-down influences (attentional control, WM), interaction between top-down and bottom-up (attentional bias to threat) influences, causal influences, and context (cognitive load).

Anxiety-related Effects on Top-down Influences: Attentional Control and Working Memory

As emphasized throughout this thesis, anxiety has been closely associated with impairments in attentional control and WM (Eysenck et al., 2007; Bishop, 2007; Berggren & Derakshan, 2013; Moran, 2016). Accordingly, as described in the previous sections, studies reported in this thesis extensively focused on this relationship. Specifically, in **chapters 3** and **4**, we focused on the influence of state anxiety and worry, respectively, on WM.

In **chapter 3**, we observed that elevated state anxiety was related to better WM performance in the presence of threat-related stimuli supporting hypervigilance (i.e. increased vigilance can lead to increased monitoring and broader attention; Eysenck, 1992), and mood congruency accounts (i.e. anxious mood can improve performance in the presence of anxiety-provoking stimuli; Bower, 1981). However, in **chapter 4**, we observed that worry was related to reductions in WM capacity. Collectively, these findings suggest that different forms of anxiety might have differential effects on top-down attentional control and WM. However, it should also be noted that performance benefits in **chapter 3** were observed in relation to threat-related stimuli and we could not observe an overall improvements in WM regardless of threat. Hence, the apparent discrepancy in our findings with regard to effects of worry and state anxiety might be due to the presence vs. absence of (task-irrelevant) threat-related stimuli. In line with this view, several studies previously reported state-anxiety-related impairments in WM when using emotionally neutral tasks to assess WM (Lavric et al., 2003; Shackman et al., 2006; Vytal et al., 2012; 2013). Relatedly, in **chapter 5** of this thesis, we examined the influence of worry on selective attention to threat; yet we failed to observe worry-related effects on threat-related information processing. Furthermore, in **chapter 5**, we also focused on top-down influences such as WM capacity on the relationship between worry and selective attention to threat. Previous research already suggested that better attentional control and WM capacity can help to resist distractor interference (Derryberry & Reed, 2002; Barrett et al., 2004), and also potentially reduce the deleterious effect of worry-related impairments on performance. However, the results of **chapter 5** did not corroborate a possible modulatory effect of WMC on the relationship between worry and processing of threat-related information either.

To sum up, our findings show state anxiety-related improvements and worry-related impairments in WM. However, more research is needed considering the role of threat-related processes to get a clearer perspective on the modulatory (and sometimes opposite depending on the actual context) effects of different forms of anxiety on top-down influences. Furthermore, although state anxiety was related to performance benefits in the presence of threat-related stimuli (**chapter 3**), such relationship could not be observed in relation to worry (**chapter 5**). However, discrepancies in these findings might also be due to different methodological approaches we adopted in two studies; such as relevance of threat-related stimuli to the task. Our results in **chapter 5** also failed to show that top-down factors such as WM capacity could possibly reduce the adverse effects of worry on selective attention to threat. Non-significant results of this chapter will be discussed further in the limitations section here below.

Interaction Between Top-Down and Bottom-Up Influences

Chapter 2 addressed the effects of early attentional bias to threat-related stimuli on subsequent information processing stages. In this study, we observed a trend indicating that increased attentional bias to threat-related stimuli was related to decreased processing efficiency of performance in the subsequent processes at high level of trait anxiety. This finding is compatible with previous theoretical accounts proposing increased attentional bias towards threat in high-anxious population (Williams et al., 1998; Mogg & Bradley, 1998; Bar-Haim et al., 2007). Furthermore, this finding is of particular importance since several theoretical models in anxiety emphasized that early-information processing biases can influence subsequent stages of information processes, however with scant empirical evidence gathered so far in the literature confirming this conjecture (Beck & Clark, 1997; Hirsch & Mathews, 2012). According to these models, biased information processing may lead to dysfunctional cognitive strategies such as worry; and as such it may have a crucial role in the etiology and maintenance of anxiety disorders.

The new findings of **chapter 2** were different from those reported in **chapter 3** where we mainly focused on state anxiety, and observed there state anxiety-related improvements in WM in the presence of threat-related stimuli. Together these findings suggest that while trait anxiety has detrimental effects on WM, state anxiety can possibly have adaptive consequences, being associated with improvements in WM performance in the presence of threat-related stimuli. However, this interpretation should be taken cautiously due to different methodological approaches we had in these two studies (different tasks, different assessment techniques).

Furthermore, in **chapter 2**, more efficient encoding of faces in relation to high trait anxiety might also be considered as an anxiety-related benefit. Although, high trait anxiety was related to reduced processing efficiency in subsequent stages of information processing in the presence of threat-related faces, behavioral performance did not differ as a function of anxiety. Interestingly, these results raise the question of whether trait anxiety is actually related to performance benefits or costs. To clarify this issue, future research is needed focusing on better characterizing the boundaries for processing gains or costs during information processing (in the presence vs. absence of threat-related in formation in the environment) related to either state or trait anxiety (at the sub clinical level).

Causal Influences

Several chapters in this dissertation also focused on causal status of anxiety and cognitive processes. Specifically, **chapter 4** focused on the influence of worry component of anxiety on WM capacity. The findings of this investigation were in line with previous theoretical accounts proposing that worry consumes limited, albeit important cognitive resources leading thereby to impairments in WM capacity (Hirsch & Mathews, 2012; Eysenck et al., 2007; see also Moran, 2016 for a review); and suggest the existence of a causal link between worry and reduced WM capacity. However and as a caveat, we note that this causal influence is not fully established, since the effects were not directly found in association to the manipulation, but in response to individual variations as a function of the worry manipulation. Results of **chapter 4** are also consistent with previous findings demonstrating a direct influence of worry in impaired attentional control (Hayes et al., 2008; Stefanopoulou, Hirsch, Hayes, Adlam, & Coker, 2014). Given these findings, new intervention techniques to improve WM capacity (such as WM training) might be beneficial (to apply in individuals with high vulnerability to worry) in order to decrease the deleterious influence of worry-related impairments on WM functioning. Accordingly, in **chapter 6,** such training was applied in high-trait-anxious sample and promising findings were obtained.

The findings reported in **chapter 6** indicated beneficial effects of WM training in attentional control and they also suggest some reduction in anxious symptomology resulting from this specific training. Furthermore, the results obtained with regard to the Flanker task with stress vs. safe condition showed that training-related gains were observed specifically under stressful conditions where anxiety-related effects in WM are typically more evident (i.e. Sorg & Whitney, 1992; Edwards, Edwards, & Lyvers, 2015; also see Eysenck, 1992). However, the findings with regard to the antisaccade task with emotional content were less conclusive. It has been suggested that an emotional WM training might be more useful to observe training-related gains on tasks with emotional content (Schweizer, Hampshire, & Dalgleish, 2011). The findings of **chapter 6** open new research avenues to explore such as; (1) the effects of emotional WM training on attentional control and anxious symptomatology; (2) the long-term effects of WM training on attentional control and anxiety; and (3) the underlying (neurocognitive) mechanisms that WM training is possibly targeting. Eventually, such training may also be applied in clinically-anxious sample which may potentially benefit from improvements in attentional control and WM.

Context: Cognitive Load

Some of the new experimental results reported in this thesis also concerned cognitive (WM) load effect in relation to anxiety (**chapter 2**, and **3;** also see **chapter 4** for exploratory analyses). In **chapter 2**, anxiety-related effects were observed in high compared to low cognitive load. Furthermore, in **chapters 3** and **4**, state anxiety/worry-related effects were observed particularly under high cognitive load condition. As such, our findings are in line with previous studies where anxiety-related effects were detected only under high cognitive load (MacLeod & Donnellan, 1993; Berggren, Koster, & Derakshan, 2012; Qi et al., 2014a; Qi et al, 2014c); but also the attentional control theory (Eysenck et al., 2007) which proposes that anxiety-related effects are most evident when the task is cognitively demanding (also see Berggren & Derakshan, 2013). Our findings with regard to load effect also suggest that in everyday life, high-anxious individuals may not experience much problems while performing simple, routine tasks; however, anxiety-related effects may possibly interfere with task-related behavior when anxious individuals need to perform more challenging or demanding (cognitive) tasks, tapping into WM and attention control.

LIMITATIONS AND FUTURE DIRECTIONS

The different studies reported in this dissertation also had several limitations. In this section, these limitations are addressed and also recommendations for future research are provided.

A first limitation is related to the characteristics of the subjects recruited. Although the main focus of this thesis was on cognitive risk factors of anxiety and anxiety disorders, studies were conducted either in healthy (see **chapters 2, 3, 4 and 5**) or subclinical-anxious (see **chapter 6**) individuals. However, influence of anxiety on cognitive performance can differ in healthy and patient populations. For instance, state anxiety (Vytal, Arkin, Overstreet, Lieberman, & Grillon, 2016), and worry (Stefanopoulou et al., 2014) might impair WM even more in patient population (where clinical levels of negative affect are evidenced). Nevertheless, our investigations might still be helpful to understand cognitive vulnerability to anxiety which is an important risk factor for clinical anxiety (Eysenck, 1992). However, in order to gain more insight into the clinical implications of the current findings, future research is recommended in clinically-anxious samples.

Secondly, we primarily focused on the role of either trait anxiety (see **chapters 2 and 6**) or state anxiety/worry (see **chapters 3, 4 and 5**) in our studies. However, although trait and state anxiety are highly correlated (Eysenck, 1992), the interaction between trait and state anxiety can also influence information processing in several and (often) non-transparent ways: for example several studies already demonstrated that individuals high in state anxiety have greater attentional bias towards threat (MacLeod & Mathews, 1988; MacLeod & Rutherford, 1992); and impaired WM (Egloff & Hock, 2001) if they are also high in trait anxiety concurrently. Hence, future studies are recommended to pre-select participants in high and low trait anxiety while investigating the role of state worry/anxiety on performance in order to explore the full scope of interactions effects between state and trait anxiety.

Thirdly, in the studies where we investigated anxiety-related processes considering task difficulty (specifically, **chapters 2 and 3**), we focused on only the effects of cognitive (WM) load in relation to anxiety, yet influences of perceptual load was not investigated in any of these chapters. However, cognitive and perceptual load can have different effects on task performance. For instance, as opposed to high cognitive load, high perceptual load can be related to reduced interference by distractor (see Lavie, Hirst, de Fockert, & Viding, 2004; Lavie, 2005). Accordingly, studies focusing on perceptual load observed anxiety-related impairments in performance only under low perceptual load (Bishop, Jenkins, & Lawrence, 2007; Bishop, 2009). Hence, in order to fully understand how task demands influence performance in relation to anxiety, future studies are recommended considering the role of both cognitive and perceptual load.

Although in several chapters of this dissertation, we focused on both processing efficiency (neurophysiological measures; ERPs) and performance effectiveness, in some of them, we only relied on behavioral measures which might be reflecting only the performance effectiveness. For example, in **chapter 5**, in order to observe threat-related processes, we focused on behavioral measures (reaction times); whereas worry-related effects might have emerged in processing efficiency (such as cognitive effort invested to perform the task) which was not examined in this chapter however. In a similar vein, in **chapter 2**, we did not observe anxiety-related effects on WM performance at the behavioral level either; but modulatory effects of anxiety on WM performance with regard to load and emotion only emerged at the ERP level. It is also noteworthy to mention that, in **chapters 3** and **4**, anxiety-related effects were observed at the behavioral level; yet only under high cognitive load condition when anxious individuals might not be able to utilize compensatory strategies to maintain performance effectiveness (see Berggren & Derakshan, 2013). However, in **chapter 2**, even under high cognitive load condition, anxiety-related effects were not observed in behavioral outcome measures. One possible explanation for that observation could be due to differences in task demands between these two studies; such as set size. For instance, while participants were asked to attend to 4 items in **chapter 4**; participants encoded only 2 items in **chapter 2** during the high cognitive load condition. However, in order to have a better understanding of mechanisms underlying anxiety-related effects on performance under various task demands, future studies are warranted, preferably focusing on both effectiveness and efficiency of performance.

Lastly, throughout this dissertation, we mainly focused on attentional bias towards threat. However, anxiety might also be related to biases in interpretation of ambiguous information; long-term memory or future expectations (Beck, Emery, & Greenberg, 1985; Mathews & MacLeod, 1994; Mathews, Mackintosh, & Fulcher, 1997; Bishop, 2007; Grupe & Nitschke, 2013). These factors have not been considered within the scope of this dissertation. It might be valuable to focus on each of these biased processes in order to have a full perspective on cognitive vulnerability to anxiety.

CONCLUDING REMARKS

In this thesis, cognitive vulnerability factors to anxiety were investigated by means of experimental research carried out using a modern cognitive psychopathology framework. In accordance with the dominant cognitive theories in anxiety available in the literature (i.e. Eysenck, 1992; Beck & Clark, 1997; Eysenck et al., 2007), our findings demonstrated a close link between anxiety, attentional control and WM, although the direction and strength of this complex relationship appear to vary depending on specific task demands and contextual factors. As such, we hope that the studies reported in this thesis could contribute to gain a better understanding of the relationship between attentional bias towards threat-related information considering several forms of anxiety and subsequent stages in information processing; the causal status of worry and reductions in WM capacity; and also the causal status of attentional control and anxiety. Because some of these studies yielded inconclusive results and await replication, we believe that future research in experimental psychopathology is recommended at this stage, considering the above-mentioned limitations, with the aim to eventually gain a better understanding of the nature and extent of vulnerability factors for anxiety. This research line may eventually be valuable to prevent the development and maintenance of anxiety at a clinical level, which is associated with debilitating consequences for the health and well-being.

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Nederlandstalige Samenvatting

Onderzoeksdoelen

Angst wordt omschreven als een aversieve, negatieve emotionele toestand, die optreedt bij het waarnemen van bedreiging (Rachman, 1998). Vanuit een evolutionair gezichtspunt, kan angst beschouwd worden als een adaptieve emotionele toestand die nuttig kan zijn bij het opmerken van de eerste tekenen van gevaar (Eysenck, 1992; Clark & Beck, 2011). Echter, bij afwezigheid van onmiddellijke dreiging, kan angst maladaptief zijn, wat vaak het geval is bij angststoornissen (Barlow, 2002; Gray & McNaughton, 2003; Clark & Beck, 2011).

Angststoornissen behoren tot de meest voorkomende psychische stoornissen in de samenleving (Baxter, Scott, Vos, & Whiteford, 2013). Inzicht in de risicofactoren waardoor deze stoornissen ontstaan en voortbestaan, is dan ook van groot belang. Onder de vele mogelijke risicofactoren - waaronder genetica, vroege levenservaringen, trauma, en persoonlijkheidsfactoren (Barlow, 2000), worden cognitieve risicofactoren benadrukt. Cognitieve factoren blijken een centrale rol te spelen bij angst, en dit bij verschillende angststoornissen (Eysenck, 1992; Eysenck & Calvo, 1992; Beck & Clark, 1997; Williams, Watts, MacLeod & Matthews, 1988; Mogg & Bradley, 1998; Eysenck, Santos, Derakshan, & Calvo, 2007; Grupe & Nitschke, 2013). Cognitieve modellen benadrukten vaak dat angst gerelateerd is aan vertekeningen in de informatieverwerking bij confrontatie met bedreigende stimuli (Beck & Clark, 1997; Williams et al., 1998; Mogg & Bradley, 1998; Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van Ijzendoorn, 2007); maar ook algemene beperkingen in cognitieve mechanismen, zoals het werkgeheugen (WG) en aandachtscontrole (Eysenck, 1992; Eysenck et al., 2007; Berggren & Derakshan, 2013).

Het WG is een geheugensysteem met beperkte capaciteit, en wordt gebruikt om complexe problemen op te lossen (Baddeley, 1992). WG capaciteit wordt uitgedrukt in termen van iemands vermogen om relevante informatie te verwerken, terwijl afleidende informatie genegeerd wordt. WG processen hangen nauw samen met aandachtscontrole (Baddeley, 2003; Gazzaley & Nobre, 2012; Shipstead, Lindsey, Marshall, & Engle, 2014). Bijgevolg kan gebrekkige aandachtscontrole een efficiënte werking van het WG verhinderen. Aandachtscontrole is gebaseerd op de interactie tussen twee subsystemen: een bottom-up en top-down systeem (Corbetta & Shulman, 2002; Theeuwes, 2010; Posner & Petersen, 1990). Terwijl het bottom-up systeem stimulus-gedreven en reflexief is; is het top-down systeem doelgericht en vrijwillig. De interactie tussen deze subsystemen is belangrijk, omdat deze bepaalt in welke mate individuen in staat zijn om irrelevante informatie te inhiberen, en gefocust te blijven op hun huidige doelstellingen (Pashler, Johnston, & Ruthruff, 2001; Barrett, Tugade, & Engle, 2004).

Op basis van cognitieve standpunten en theoretische benaderingen van angst, hebben we ons in het huidige proefschrift gericht op angst-gerelateerde vertekeningen en beperkingen in belangrijke cognitieve factoren die de kwetsbaarheid voor angst verhogen. Meer bepaald, hebben we bottom-up invloeden onderzocht, zoals aandachtbias voor bedreiging (neiging om bedreigende informatie op te merken in de omgeving op te merken en hierop gefocust te blijven; Bar-Haim et al., 2007; **hoofdstuk 2, 3, en 5**), alsook algemene beperkingen in top-down aandachtscontrole en WG (**hoofdstuk 4 en 6**). Tevens werden verschillende vormen van angst onderzocht, waaronder toestandsangst (tijdelijke emotionele toestand in reactie op situaties die als bedreigend worden ervaren; Spielberger, 1972, **hoofdstuk 3**), trekangst (een stabiele individuele eigenschap om de neiging te hebben angst te ervaren, Spielberger, 1972, **hoofdstuk 2 en 6**), en piekeren (toestand waarbij oncontroleerbare, opdringerige, negatieve gedachten over de toekomst optreden; Borkivec, Robinson, Pruzinsky & DePree, 1983, **hoofdstuk 4 en 5**). Tenslotte, werden ook de invloed van de context (taakvereisten zoals cognitieve belasting, **hoofdstuk 2 en 3**) en de causale relatie tussen angst en WG (**hoofdstuk 4 en 6**) onderzocht. In de volgende paragraaf, worden deze onderzoeksdoelen en de belangrijkste resultaten kort samengevat.

OVERZICHT VAN HOOFDSTUKKEN EN HOOFDBEVINDINGEN

Hoofdstuk 2 focuste op hoe vroege aandachtsbias voor bedreiging invloed heeft op de volgende stappen van informatieverwerking. Gezien de adverse effecten van dispositie voor angst op performantie evidenter kunnen zijn onder een hoge cognitieve (zie Berggren & Derakshan, 2013), werd ook de invloed van cognitieve (werkgeheugen; WG) lading bekeken in dit onderzoek. In deze studie hebben we een taak afgenomen waar emotie (neutrale vs. angstige gezichten) en WG lading (lage vs. hoge lading) gemanipuleerd werden en opgeslagen diende te worden in et werkgeheugen. We maten zowel gedragsindices als event related potentials (ERPs). Op ERP-niveau focusten we op de N170 (voor het encoderen van gezichtsstimuli, vroege verwerking), en de CNV (contingente negatieve variatie; voor het onderhouden van informatie, anticiperende cognitieve inspanning, late verwerking). Onze resultaten waren de volgende: (1) enkel het effect van WG lading verscheen op gedragsniveau; (2) N170 activiteit was gemoduleerd door WG lading en angst, wat aantoont dat hoog-angstige individuen een grotere N170 hadden onder een hoge WG lading vergeleken met onder een lage lading; (3) CNV activiteit was gemoduleerd door WG lading, emotie en angst, wat aantoont dat hoge angst gerelateerd was aan lagere CNV activiteit in de hoge WG lading conditie vergeleken met die met een lage lading, in de aanwezigheid van angstige gezichten; (4) Ten slotte was er een trend die een omgekeerde relatie aantoonde tussen N170 en CNV activiteit in de aanwezigheid van angstige gezichten, als een functie van WG lading en dit was evidenter bij hoog-angstige individuen. Deze resultaten zijn de eerste om een mogelijke connectie aan te tonen tussen een verbeterde verwerking van angstige gezichten (geïndexeerd door N170 activiteit) en een gereduceerde verwerkingsefficiëntie van het WG (geïndexeerd door CNV activiteit) als reactie op taakvereisten in individuen met een verhoogde dispositie voor angst.

Hoofdstuk 3 focuste op de rol van situationele angst op het WG, rekening houdend met cruciale factoren die mogelijk bijdragen aan deze relatie: emotie (bedreigingsgerelateerde vs. neutrale stimuli) en cognitieve lading (hoge vs. lage lading). Om het effect van situationele angst op WG te onderzoeken, rekening houdend met taakvereisten (lage vs. hoge cognitieve lading) en emotionaliteit (bedreigingsgerelateerde vs. neutrale stimuli), werd een emotionele variant van de WG taak gebruikt door de Fockert, Rees, Frith en Lavie (2001) afgenomen. Vooraleer deze taak van start ging, werd situationele angst gemanipuleerd door dreiging met shock. Resultaten toonden dat situationele angst (zelfgerapporteerde angstscores na de manipulatie; alsook veranderingen in deze scores van pre- naar post-manipulatie) een omgekeerde relatie had met interferentie door bedreigingsgerelateerde stimuli in de conditie met een hoge cognitieve lading. Gelijkaardige bevindingen werden niet gevonden in de conditie met een lage cognitieve lading. Dit onderzoek kan nuttig zijn om een beter begrip te bekomen van de effecten van situationele angst op WG performantie, rekening houdend met emotionaliteit en taakvereisten in gezonde volwassen subjecten.

In **hoofdstuk 4** werd de causale status van piekeren en WG capaciteit onderzocht. In dit onderzoek werden participanten toegewezen ofwel aan een "pieker conditie" waar ze gevraagd werden te focussen op een zorgwekkende gedachte; ofwel aan een controleconditie waar ze gevraagd werden te focussen op een positief onderwerp (cf. Hayes, Hirsch, & Mathews, 2008). Om WG capaciteit te kunnen beoordelen, voerden participanten een veranderingsdetectietaak uit (Vogel, McCollough, & Machizawa, 2005) voor (pre-manipulatie) en na (post-manipulatie) een pieker inductie of een controleprocedure. Resultaten toonden aan dat participanten in de pieker conditie een verminderde WG capaciteit hadden tijdens de post- in vergelijking met de pre-manipulatie, gerelateerd aan verhoogde zorgen. Bevindingen van dit onderzoek zijn belangrijk aangezien ze een directe relatie suggereren tussen piekeren en WG capaciteit.

In **hoofdstuk 5** onderzochten we de relatie tussen piekeren en aandachtsbias naar bedreiging, rekening houdend met de modulaire rol van de WG capaciteit. Om de WG capaciteit te beoordelen, voerden participanten eerst een veranderingsdetectietaak uit (Vogel et al., 2005). Daarna werden ze toegewezen aan ofwel een pieker ofwel een controleconditie, waar een pieker manipulatie of een controleprocedure werd gevolgd. (cf. Hayes et al., 2008). Nadien voerden participanten een visuele zoektaak uit met boze, blije of neutrale gezichten (cf. Derakshan & Koster, 2010) om de bedreigingsgerelateerde aandachtsbias na te gaan. Op basis van de visuele zoektaakperformantie werden verscheidene aandachtsbiasindices berekend, gecontroleerd voor engagement voor bedreigingsgerelateerde stimuli (boze gezichten) en disengagement voor zulke stimuli. Resultaten toonden dat conditie (piekeren vs. controle) geen effect had, op geen enkele van de aandachtsbiasindices. Bovendien werd de relatie tussen conditie en de aandachtsbiasindices ook niet gemodereerd door WG capaciteit. De bevindingen van **hoofdstuk 5** zijn dus niet overtuigend met betrekking tot de invloed van piekeren op aandachtsbias naar bedreiging en de rol van WG capaciteit op deze relatie.

In **hoofdstuk 6** werd de causale status van de relatie tussen angst en problemen in aandachtscontrole en WG verkend door WG training. In dit onderzoek bekeken we de effecten van WG training op aandachtscontrole, alsook de zelfgerapporteerde angstige symptomatologie in voorgeselecteerde (subklinische) individuen met predispositie om hoog-angstig te zijn. Participanten werden toegewezen aan ofwel een trainingsconditie waar ze een dual N-back taak uitvoerden (Jaeggi et al., 2003) ofwel een actieve controleconditie waar ze een niet-adaptieve versie van de taak uitvoerden. De training/controle interventie duurde drie weken (15 sessies). Voor en na deze interventie werden participanten uitgenodigd naar het lab om computertaken uit te voeren die aandachtscontrole en WG beoordelen (Resting State EEG, Flankertaak – met veilige en stresserende condities, antisaccadetaak – met boze of neutrale gezichten); en ook vragenlijsten invulden met betrekking tot angst, zorgen en aandachtscontrole. In deze studie observeerden we trainingsgerelateerde verbeteringen in aandachtscontrole (gezien in resting state EEG); verbeteringen in flankertaakperformantie in de stresserende conditie; en ook verminderde zelfgerapporteerde angst gerelateerd aan verbeteringen in de trainingstaak. Trainingsgerelateerde verbeteringen konden echter niet geobserveerd worden in de antisaccadetaak met emotionele gezichten. In het algemeen suggereren onze resultaten dat WG training in angstige individuen gunstige effecten kan hebben.

Theoretisch een Praktische Implicaties

De focus van **hoofdstuk 4** had betrekking tot de invloed van piekeren (de cognitieve component van angst) op werkgeheugencapaciteit. Resultaten gevonden in deze studie suggereerden een causale link tussen piekeren en verminderde werkgeheugencapaciteit. Deze bevindingen zijn in lijn met voorgaande theoretische kaders die voorstellen dat piekeren cognitieve bronnen (die beperkt zijn) consumeert en dit leidt tot tekortkomingen in werkgeheugencapaciteit (Hirsch & Mathews, 2012; Eysenck et al., 2007; zie eveneens Moran, 2016 voor een review). Gebaseerd op de bevindingen van **hoofdstuk 4**, zouden interventietechnieken die gericht zijn op het verbeteren van werkgeheugencapaciteit (zoals werkgeheugentraining) voordelig kunnen zijn voor individuen die veelvuldig piekeren, om zo de invloed van piekeren op werkgeheugen capaciteit te beperken. Dit soort training werd vervolgens in **hoofdstuk 6** toegepast in hoog angstige subjecten (bij angst kan gezien worden als trek); hierbij observeerden we training gerelateerde verbeteringen in werkgeheugen, aandachtscontrole alsook in zelfgerapporteerde symptomatologie van angst. Desondanks werden geen trainingsgerelateerde verbeteringen geobserveerd in de antisaccade taak met emotionele inhoud. De bevindingen van **hoofdstuk 6** zijn suggestief/aanmoedigend voor toekomstig onderzoek omtrent emotionele werkgeheugentraining; lange termijn effecten van werkgeheugentraining; en onderliggende mechanismen waarop werkgeheugentraining mogelijks richt.

Hoofdstuk 2, 3, en **5** van deze uiteenzetting focuste op een aandachtsbias voor bedreiging waarbij meerdere vormen van angst in rekening werden gebracht. De resultaten van **hoofdstuk 2** suggereerden een mogelijke link tussen vroege aandachtsbias voor bedreiging en een vermindering in de daaropvolgende verwerking van informatie geassocieerd met hogere niveaus van trekangst. Deze bevinding ondersteunt verschillende theoretische kaders omtrent angst die voorstellen dat vertekeningen/biases tijdens vroege verwerking van informatie een grote impact kunnen hebben op verdere verwerking van informatie en kan leiden tot dysfunctionele cognitieve strategieën zoals bezorgdheid (Beck & Clark, 1997; Hirsch & Mathews, 2012). **Hoofdstuk 5** focuste dan weer op de relatie tussen bezorgdheid en aandachtsbias. In deze studie vonden we echter geen relatie tussen bezorgdheid en aandachtsbias voor bedreiging. Een mogelijke verklaring hiervoor kan liggen bij de ‘processing efficiency account’ van angst (Processing efficiency theory; Eysenck & Calvo, 1992; Attentional control theory, Eysenck et al., 2007). Volgens deze theorieën zou angst voornamelijk de efficiëntie van verwerking verminderen (de relatie tussen de uitkomst van een prestatie en het gebruik van cognitieve bronnen; vaak gemeten via neurofysiologische maten) in plaats van de effectiviteit van prestaties (de uitkomst van prestaties; vaak gemeten via gedragsmaten). In **hoofdstuk 5** baseerden we ons enkel op gedragsmaten (reactietijden; die kunnen gezien worden als een maat van effectiviteit van prestaties) om aandachtsbias voor bedreiging te onderzoeken (Eysenck & Derakshan, 2011; Basten, Stelzel, & Fiebach, 2012); terwijl bezorgdheid-gerelateerde effecten mogelijks tot uiting kwamen in de efficiëntie van verwerking, werden deze niet onderzocht in **hoofdstuk 5**. Bijkomend werden er in **hoofdstuk 2** ook geen angst-gerelateerde effecten (op gedragsniveau) op werkgeheugenprestaties gevonden, maar deze effecten manifesteerden zich wel op ERP niveau. Ten laatste onderzochten we de rol van situationele angst op aandachtsbias voor bedreiging in **hoofdstuk 3**. In tegenstelling tot de bevindingen in **hoofdstuk 2**, waar we vermindering in prestatie terugvonden in relatie met trekangst en aandachtbias voor bedreiging, observeerden we in **hoofdstuk 3** situationele angst-gerelateerde voordelen voor prestaties wanneer zij in de aanwezigheid waren van bedreigingsgerelateerde stimuli.

Verschillende onderzoeken in deze thesis focusten ook (**hoofdstuk 2** en **3**; alsook **hoofdstuk 4** ter exploratie) op het effect van cognitieve belasting. In deze hoofdstukken observeerden we dat angst-gerelateerde effecten meer uitgesproken waren tijdens een conditie van hoge cognitieve belasting. Deze bevindingen zijn in lijn met vorige studies waarbij angst-gerelateerde effecten enkel voorkwamen bij hoge cognitieve belasting, wanneer de taak meer vereiste (MacLeod & Donnellan, 1993; Berggren, Koster, & Derakshan, 2012; Qi, Chen, Hitchman, Zeng, Ding, Li, & Hu, 2014a; Qi, Zeng, Luo, Duan, Ding, Hu & Li, 2014c). Onze bevindingen met betrekking tot het effect van belasting suggereert ook dat in het dagelijkse leven, hoog angstige individuen deze problemen niet ervaren bij simpele geroutineerde taken; angst-gerelateerde effecten kunnen echt wel interfereren met het dagelijkse leven wanneer men moet presteren op uitdagende taken.

BEPERKINGEN EN TOEKOMSTIG ONDERZOEK

De studies gerapporteerd in deze thesis hebben ook enkele beperkingen. Alhoewel het algemene doel van deze thesis bestond uit het beter begrijpen van cognitieve kwetsbaarheidsfactoren bij angst en angststoornissen, werden de studies uitgevoerd met enkel een steekproef van gezonde volwassenen. Ten tweede focusten we ofwel op de rol van trekangst (**hoofdstuk 2** en **6**) ofwel op de rol van situationele angst/bezorgdheid (**hoofdstuk 3, 4** en **5**). Hierbij werd de interactie tussen situationele angst en trekangst niet in rekening gebracht. Ten derde focusten we in onze studies enkel op de rol van cognitieve belasting; terwijl perceptuele belasting ook een behoorlijke invloed kan hebben op prestaties (zie Lavie, Hirst, de Fockert, & Viding, 2004; Lavie, 2005), werd dit niet bestudeerd. Ten laatste focusten we ons in deze thesis vooral op een aandachtsbias voor bedreiging. Angst kan echter ook gerelateerd zijn aan vertekeningen die betrekking hebben op interpretatie of geheugen (Beck, Emery, & Greenberg, 1985; Mathews & MacLeod, 1994; Mathews, Mackintosh, & Fulcher, 1997; Grupe & Nitschke, 2013).

Samengevat toonden de gerapporteerde studies in deze thesis aan dat er een nauwe link bestaat tussen angst, aandachtscontrole en werkgeheugen. Om een nog duidelijker perspectief te krijgen op angst en factoren die cognitieve kwetsbaarheid inhouden, wordt bij het voeren van toekomstig onderzoek aangeraden om de hierboven vermelde beperkingen te overwegen of in rekening te brengen.

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DATA STORAGE FACT SHEETS

% Processing emotional faces in relation to working memory load and anxiety: an event-related potential study
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* Which other files have been stored?
  - [x] file(s) describing the transition from raw data to reported results. Specify: see methodology in Chapter 2
  - [x] file(s) containing processed data. Specify: N170.xlsx; CNV.xlsx, Behavioral.xlsx, ERP.sav
  - [x] file(s) containing analyses. Specify: ERP.spv
  - [ ] files(s) containing information about informed consent
  - [ ] a file specifying legal and ethical provisions
  - [ ] file(s) that describe the content of the stored files and how this content should be interpreted. Specify: ...
  - [ ] other files. Specify: ...

* On which platform are these other files stored?
  - [x] individual PC
  - [ ] research group file server
  - [x] other: external hard drive

* Who has direct access to these other files (i.e., without intervention of another person)?
  - [x] main researcher
  - [x] responsible ZAP
  - [ ] all members of the research group
  - [ ] all members of UGent
  - [ ] other (specify): ...

4. Reproduction
===
* Have the results been reproduced independently?: [ ] YES / [x] NO

* If yes, by whom (add if multiple):
   - name:
   - address:
   - affiliation:
   - e-mail:

% The effects of state anxiety on working memory in relation to emotion and cognitive load
% Author: Berna Sari
% Date: 25.5.2016

1. Contact details
==

1a. Main researcher

- name: Berna Sari
- address: Henri Dunantlaan 2, B-9000 Gent

- e-mail: ayseberna.sari@ugent.be

1b. Responsible Staff Member (ZAP)

- name: Ernst Koster
- address: Henri Dunantlaan 2, B-9000 Gent

- e-mail: ernst.koster@ugent.be

If a response is not received when using the above contact details, please send an email to data.pp@ugent.be or contact Data Management, Faculty of Psychology and Educational Sciences, Henri Dunantlaan 2, 9000 Ghent, Belgium.

2. Information about the datasets to which this sheet applies
==
* Reference of the publication in which the datasets are reported:
Doctoral thesis - Berna Sari

* Which datasets in that publication does this sheet apply to?:
Only to the data described in the thesis.

3. Information about the files that have been stored
==

3a. Raw data
----

* Have the raw data been stored by the main researcher? [x] YES / [ ] NO
If NO, please justify:

* On which platform are the raw data stored?
  - [x] researcher PC
  - [ ] research group file server
  - [x] other (specify):external hard drive

* Who has direct access to the raw data (i.e., without intervention of another person)?
  - [x] main researcher

- [x] responsible ZAP
- [ ] all members of the research group
- [ ] all members of UGent
- [ ] other (specify): ...

3b. Other files
----

* Which other files have been stored?
- [x] file(s) describing the transition from raw data to reported results. Specify: see methodology in Chapter 3
- [x] file(s) containing processed data. Specify: StateAnxiety.sav, quest.emrg2, task.emrg2
- [ ] file(s) containing analyses. Specify:stateanxiety.spv
- [ ] files(s) containing information about informed consent
- [ ] a file specifying legal and ethical provisions
- [ ] file(s) that describe the content of the stored files and how this content should be interpreted. Specify: ...
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- address:
- affiliation:
- e-mail:

% The effects of active worrying on working memory capacity
% Author: Berna Sari
% Date: 16.3.2016

1. Contact details
==

1a. Main researcher

- name: Berna Sari
- address: Henri Dunantlaan 2, B-9000 Gent

- e-mail: ayseberna.sari@ugent.be

1b. Responsible Staff Member (ZAP)

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2. Information about the datasets to which this sheet applies
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* Reference of the publication in which the datasets are reported:
Sari, B. A., Koster, E. H., & Derakshan, N. (2016). The effects of active worrying on working memory capacity. *Cognition and Emotion, 1*-9.

* Which datasets in that publication does this sheet apply to?:
Only to the data described in the article.

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- [ ] all members of UGent
- [ ] other (specify): ...

3b. Other files
----

* Which other files have been stored?
  - [x] file(s) describing the transition from raw data to reported results. Specify: A detailed description can be found in the article.
  - [x] file(s) containing processed data. Specify: Worry1.xlsx; Worry1.sav
  - [x] file(s) containing analyses. Specify: Worry.spv
  - [ ] files(s) containing information about informed consent
  - [ ] a file specifying legal and ethical provisions
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  - address:
  - affiliation:
  - e-mail:

% The effects of active worrying on threat-related information processing considering the modulatory role of working memory capacity
% Author: Berna Sari
% Date: 16.3.2016

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 - [ ] all members of UGent
 - [ ] other (specify): ...

3b. Other files
----

* Which other files have been stored?
 - [x] file(s) describing the transition from raw data to reported results. Specify: see methodology in Chapter 5
 - [x] file(s) containing processed data. Specify: Worry2.xlsx; Worry2.sav
 - [x] file(s) containing analyses. Specify: worry2.spv
 - [ ] files(s) containing information about informed consent
 - [ ] a file specifying legal and ethical provisions
 - [ ] file(s) that describe the content of the stored files and how this content should be interpreted. Specify: ...
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* Have the results been reproduced independently?: [ ] YES / [x] NO

* If yes, by whom (add if multiple):
 - name:
 - address:
 - affiliation:
 - e-mail:

% Training working memory to improve attentional control in anxiety: a proof-of-principle study using behavioral and electrophysiological measures
% Author: Berna Sari
% Date: 22.9.2015

1. Contact details
===

1a. Main researcher

- name: Berna Sari
- address: Henri Dunantlaan 2, B-9000 Gent

- e-mail: ayseberna.sari@ugent.be

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Sari, B. A., Koster, E. H., Pourtois, G., & Derakshan, N. (2015). Training working memory to improve attentional control in anxiety: A proof-of-principle study using behavioral and electrophysiological measures. *Biological Psychology.*

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  - [ ] all members of the research group
  - [ ] all members of UGent
  - [ ] other (specify): ...

3b. Other files
----

* Which other files have been stored?
  - [x] file(s) describing the transition from raw data to reported results. Specify: A detailed description can be found in the article.
  - [x] file(s) containing processed data. Specify: Questionnaires.xlsm, Theta.xlsx, Training improvement.xlsx, Antisaccade Latency Post.xlsm, Antisaccade Latency Pre.xlsm, Beta.xlsx, Central Negativity.xlsx, Flanker.xlsx, Training.sav
  - [x] file(s) containing analyses. Specify: training.spv
  - [ ] files(s) containing information about informed consent
  - [ ] a file specifying legal and ethical provisions
  - [ ] file(s) that describe the content of the stored files and how this content should be interpreted. Specify: ...
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   - e-mail: