Losing control : anxiety and executive performance

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Chapter 8

General discussion

Summary of findings

The aim of this thesis is to provide insights in the relationship between anxiety, attentional bias (AB) to emotional information, and cognitive performance by investigating the role of trait cognitive control and trait anxiety. For this purpose, we ran several studies assessing trait anxiety and manipulating stress levels. Trait cognitive control was assessed objectively with frontal EEG theta/beta ratio (TBR) and with a self-report measure. AB to emotional information was assessed objectively with different tasks using pictorial or word stimuli, and subjectively with a self-report measure. Executive cognitive performance was assessed with different working memory (WM) tasks. Finally cognitive control was manipulated with a 40 mg hydrocortisone-administration. All experiments were conducted on healthy samples, including healthy samples with high levels of trait anxiety. First, a summary of the findings is reported, that will be further discussed.

In chapter 2, the negative relationship between frontal EEG TBR and self-report attentional control was replicated. TBR was also predictive of self-report attentional control over a 1-week interval. Finally, it was found that the 1-week test-retest reliability of frontal TBR was excellent. This evidence further supports the notion that frontal TBR is possibly a reliable electrophysiological marker for trait attentional control.

In chapter 3, lower frontal TBR (assumed to reflect higher cognitive control) was associated with higher AB towards high threat (HT) compared to mild threat (MT), measured with a dot-probe task. Moreover, this relationship was moderated by trait anxiety. Specifically, the most resilient individuals, with higher cognitive control and lower trait anxiety, showed higher AB towards HT compared to MT. The relationships were independent of the time-course of attention (200 ms vs 500 ms). These results further support the interacting role of trait cognitive control and trait anxiety, for the first time, in their relation to threat-related AB. Moreover, these results underline the importance of investigating the attentional processing of distinct levels of threat. It is further shown, for the first time, that TBR predicts executive control over emotional spatial attentional processing.

In chapter 4, the relationship between TBR and AB to HT compared to MT was replicated, using a dot-probe task with a probe-delay of 80 ms and 200 ms. This association was irrespective of probe-delay or trait anxiety. Moreover, higher self-report attentional control was related to higher AB towards HT compared to MT in the later stages of attention (200 ms) but not earlier (80 ms). The present evidence further supports the conclusions in chapter 3 with subjective and objective measures for trait attentional control.

In chapter 5, individuals in a performance-like stress group, who went through the Leiden-Performance Anxiety Stress Test (L-PAST), showed higher objective (heart rate and cortisol levels) and subjective levels of stress, and slower responses during an *n*-back task, as compared to a control group. Both effects were moderated by trait cognitive test anxiety, indicating that the stressed

individuals with higher trait cognitive test anxiety showed higher levels of stress and they were slower during WM performance. Moreover, individuals in the stress group with higher trait cognitive test anxiety showed higher objective interference from negative stimuli during the higher but not lower WM load (3-back vs 2-back). Importantly, all the moderating effects were specific to trait cognitive test anxiety but not general trait anxiety, supporting the validity of L-PAST as a laboratory procedure that induces acute cognitive performance anxiety (CPA).

In chapter 6, the effects of acute stress, induced with the Trier Social Stress Test (TSST), on objective and subjective threat-interference were moderated by TBR and self-report trait attentional control respectively. Specifically, TBR interacted with trait anxiety moderating the effects of stress on threat-interference as assessed with an emotional Stroop task. Moreover, TBR moderated the effect of acute stress on objective interference from negative evaluation words during an arithmetic task, indicating that individuals with higher trait cognitive control (lower TBR) showed lower threat-interference during their performance. The results further showed that trait cognitive test anxiety moderated the effects of stress on WM performance, assessed with an *n*-back task and an arithmetic task. The present study shows, for the first time, the important role of trait cognitive control, also in interaction with trait anxiety, on the effects of acute stress on threat-interference. Moreover, TBR is suggested, for the first time, as marker for control over emotional information under acute stress. Finally, the present evidence underlines the role of trait anxiety on the effects of stress on cognitive performance.

In chapter 7, individuals in the hydrocortisone group with higher cognitive control (lower TBR) and higher trait social anxiety showed less interference from HT compared to MT under acute stress, compared to the placebo group. Moreover, individuals with higher self-report attentional control and lower trait social anxiety, or general trait anxiety, in the hydrocortisone group, compared to the placebo group, showed lower interference from erotic stimuli. Finally, individuals in the hydrocortisone group reported higher levels of state attentional control. The present evidence suggests that hydrocortisone-administration of 40 mg increases state attentional control while it reduces interference from highly arousing emotional stimuli under acute stress in vulnerable highly anxious females with higher trait cognitive control, effects that vary depending on trait social anxiety.

The findings of this thesis as well as their limitations and potential implications will be further discussed along the main themes of this thesis.

Frontal EEG Theta/beta ratio

Trait cognitive control is one of the main concepts investigated in this thesis, as a crucial factor in relation to anxiety and executive performance. As TBR is suggested to reflect cortical-subcortical interactions (Knyazev, 2007; Schutter &

Knyazev, 2012) such as in cognitive control, in the current thesis frontal EEG TBR was further investigated as a marker for trait cognitive control and specifically over emotional information. TBR received initial attention in relation to ADHD. This research related TBR to PFC-mediated attentional deficits (Clarke et al., 2007; Loo et al. 2016; for a review, see Arns et al., 2013). Recent evidence associated TBR with lower executive control in healthy individuals. Specifically, lower TBR has been related to higher self-report trait and state attentional control (Putman, van Peer, Maimari, & van der Werff, 2010; Putman, Verkuil, Arias-Garcia, Pantazi, & van Schie, 2014). In the current thesis, we first replicated this relation and we further found that TBR was predictive of self-report trait attentional control in a 1-week interval (Angelidis, van der Does, Schakel, & Putman, 2016). Moreover, we replicated the negative relationship between TBR and self-report trait attentional control again in chapter 4 (van Son, Angelidis, Hagenaars, van der Does, & Putman, 2018a). However, it should be mentioned that there are studies, in this thesis (chapters 3, 6, and 7) and others, that did not find this association (Angelidis, Hagenaars, van Son, van der Does, & Putman, 2018; Angelidis, Chalkia, van der Does, & Putman, submitted; Angelidis, Kyrgiou, van der Wee, van der Does, & Putman, submitted; Morillas-Romero, Tortella-Feliu, Bornas, & Putman, 2015; van Son, Schalbroeck, Angelidis, van der Wee, van der Does, & Putman, 2018b). A possible reason for these non-replications may be that TBR reflects general executive control, as it is suggested by the literature reported in this thesis, while the Attentional Control Scale (ACS; Derryberry & Reed, 2002) measures specific attentional functions of executive control (attentional inhibition and attentional shift). Besides, ACS is a self-report measure and its validity can thus be questioned. It has been suggested that ACS assesses individuals' believes rather than capability to control their attention (Quigley, Wright, Dobson, & Sears, 2017). ACS and its validity will be further discussed in a following section of this chapter. The last decade, there has been accumulating evidence suggesting that TBR reflects executive control, assessed with objective measures (Keune et al., 2017; Keune et al., 2019; Morillas-Romero et al., 2015; Sari, Koster, Pourtois, & Derakshan, 2015). Moreover, a recent study in our lab found that TBR is increased during mind wandering episodes (van Son, De Blasio, Fogarty, Angelidis, Barry, Putman, 2018c), a phenomenon that has been related to decreased attentional control (McVay & Kane, 2009; Unsworth & McMillan, 2014). Thus, it is highly possible that the absense of the TBR-ACS relationship in some studies is due to the reduced validity of the self-report scale rather than TBR not reflecting trait executive control.

As previously mentioned, TBR has been suggested to reflect cognitive control over specifically emotional information (Morillas-Romero et al., 2015a). Accumulating evidence, also in this thesis (chapters 3, 4, 6, and 7), supports that lower TBR is indeed related to enhanced cognitive-affect regulation, in relation to behavioral inhibition of negative information (Putman et al., 2010a),

spontaneous emotion regulation (Tortella-Feliu, Morillas-Romeo, Balle, Llabres, Bornas, Putman, 2014) and stress-induced decline of state attentional control (Putman et al., 2014). Even though trait cognitive control is suggested to be an important factor in AB, there was no prior evidence associating TBR with AB to emotional information. In chapters 3 and 4, TBR was associated, for the first time, with AB to negative information in healthy individuals (Angelidis et al., 2018; van Son et al., 2018a). Since lower TBR reflected resilience against the negative effects of acute stress on self-report state attentional control (Putman et al., 2014), an effect that is related to increased bottom-up processing and decreased top-down control, it was a meaningful next step to investigate the relation between TBR and attentional processing of emotional informaiton under acute stress. In chapter 6, it was shown for the first time that TBR moderated the effects of acute stress on interference from negative evaluation-words during two different tasks in healthy individuals. In chapter 7, it was further shown that frontal TBR moderated the effect of hydrocortisone-administration on interference from HT compared to MT under acute stress (Angelidis, Kyrgiou, van der Wee, & Putman, submitted). Hydrocortisone-administration is suggested to increase PFC-mediated cognitive control over emotional information (Putman & Roelofs, 2011; Hermans, Heckens, Joels, & Fernandez, 2014). The fact that TBR moderates the effects of this pharmacon on processing of emotional stimuli further supports the notion that TBR is a marker for executive control over emotional information.

The above mentioned evidence shows the relation between TBR and processing of emotional, negative, information. In chapter 7, TBR was not related to interference from positive, erotic, information. Similarly, van Son et al. (2018b) did not find an association between TBR and interference from positive, sports-related, pictorial stimuli. It could be argued that that the relation between TBR and emotional processing is valence-specific. In both studies, however, the positive stimuli were not as arousing as the negative stimuli. Thus, it would be prudent to be cautious with any conclusions as future research should directly investigate the relation between TBR and valence-specificity.

Moreover, despite the evidence supporting the negative relationship between TBR and executive control, it is noteworthy to also discuss the negative association between TBR and trait anxiety, as observed in chapter 2 (Angelidis et al., 2016) but also in another study (Putman et al., 2010). This relationship is quite paradoxical considering the consistently observed negative association between trait attentional control and trait anxiety (also in chapters 2, 5, and 6, e.g., Angelidis et al., 2016; Angelidis et al., 2019; Bishop et al., 2007; Derryberry & Reed, 2002; Schoorl et al., 2014). A possible explanation for this paradoxical triangle of relationships may be that TBR reflects two distinct functional processes. Previous evidence has shown that higher TBR is related to disadvantegeous approach- and punishment-driven performance in a motivated decision-making task (Schutter & van Honk, 2005; Massar, Kenemans, &

Schutter, 2014; Massar, Rossi, Schutter, & Kenemans, 2012). Approach-motivated behaviour to emotional information has been suggested to be activated in order to supress anxious-related behavioral inhibition and alleviate anxious feelings (e.g., Jonas et al., 2014). This association possibly accounts for the relationship between TBR and trait anxiety. The relationship between TBR and anxiety, however, should be seen cautiously as it has been found only twice. Moreover, the positive relationship between TBR and maladaptive motivated decision-making (Schutter & van Honk, 2005; Massar, Kenemans, & Schutter, 2014; Massar et al., 2012) could be explained as a reduced top-down control over emotional processing (Putman et al., 2010b). Finally, a recent study further suppports the notion that higher TBR is not related to arousal but to reduced capacity for cognitive control (Clarke, Barry, Karamacoska, & Johnstone, 2019). Future studies should further investigate this relationship as it may have major clinical implications in an attempt to train TBR for enhancement of cognitive control with, for instance, a neurofeedback method (e.g., Keune et al., 2019) in patients with anxiety disorders, or ADHD patients that often have comorbid anxiety disorders.

Finally, in chapter 3, it was found that TBR has an excellent 1-week test-retest reliability in healthy individuals. This finding was replicated in a clinical sample in a 2-week interval (Keune et al., 2017). All in all, the discussed evidence further supports the notion that frontal TBR is likely a reliable electrophysiological tool to investigate individual differences in trait cognitive control, specifically over emotional information, also under acute stress. Further research in TBR is necessary in order to determine the exact function of TBR and its possible relation to anxiety and motivation, however, in the present thesis, it will further be referred as an objective marker for cognitive control.

Threat-related attentional bias

Executive control is suggested to be under the control of a bottom-up salience network and a top-down executive network. Anxiety disrupts the balance between these networks by increasing the processing of emotional information while directly decreasing top-down, (dl)PFC-mediated, control over emotional information (Bishop, 2008, Hermans et al., 2014). This neurobiological mechanism is manifested as AB to emotional information. Individual differences in anxiety and trait cognitive control are important factors in AB to threat. Even though a large number of studies show a positive relationship between anxiety and AB to threat (e.g., for reviews, see Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van Ijzendoorn 2007; Cisler & Koster, 2010; van Bockstaele, Verschure, Tibboel, De Houwer, Crombez, & Koster 2014), the role of trait cognitive control seems to be understudied in psychological research. This is surprising considering its purported importance (e.g., Derakshan et al., 2009; Mogg & Bradley, 2016). Furthermore, important factors such as threat-level and

the time-course of attention are often not taken into account in previous research.

In chapters 3 and 4, higher objective trait cognitive control (lower TBR) was related to higher AB towards HT compared to MT (Angelidis et al., 2018; van Son et al., 2018a). This finding was also found for self-report trait attentional control in chapter 4 (van Son et al., 2018a). Moreover, in chapter 7, executive control was enhanced pharmacologically using hydrocortisone-administration (e.g., Hermans et al., 2014). It was found that objective trait cognitive control (TBR), in interaction with trait anxiety, moderated the effect of hydrocortisone-administration on interference from HT compared to MT under acute stress (Angelidis, et al., submitted). These are the first findings supporting the role of trait cognitive control on threat-level dependent attentional processing. In line with the cognitive-motivational framework (Mogg & Bradley, 2016, 2018), it was observed that under a non-emotionally challenging condition, resilient individuals with higher trait cognitive control and lower trait anxiety, regulate and sustain their attention towards HT, compared to MT. This possibly occurs in order to process highly arousing environmental cues and regulate their negative affect. Although initial avoidance of HT may be temporarily stress-relieving, sub-optimally processed emotional information could result in subsequent negative emotionality. Avoidance is indeed a common symptom in anxiety disorders such as post-traumatic stress disorder (PTSD) and social anxiety (e.g., American Psychiatric Association; Brewin & Holmes; Williams & Moulds, 2007). It was recently found that individuals with higher post-traumatic stress symptoms and higher trait attentional control were more avoidant of HT stimuli, thereby alleviating short-term distress but alto resulting in sustained or even increased post-traumatic symptoms over time (Bardeen & Daniel, 2017). This evidence directly supports the cognitive-motivational framework suggesting that avoiding highly arousing negative stimuli is a maladaptive strategy. The current findings provide further insights in the AB literature that is commonly referring to higher AB to threat as a negative factor in anxiety. As it is observed, there is now accumulating evidence suggesting the advantageous behavior of attending HT. Hence, the previously found positive relation between trait anxiety and threat-related AB (e.g., for reviews, see Bar-Haim et al., 2007; Cisler & Koster, 2010; van Bockstaele et al., 2014) is possibly the result of these studies using MT stimuli and not HT stimuli. To illustrate, the majority of these studies used negative words, angry faces, or scenes depicting angry animals and human attack, which are less arousing and would be considered MT. Future research should further shed light on the role of trait cognitive control and anxiety on attentional processing of different levels of threat in healthy, but also in clinically anxious populations, possibly providing further insights into the maintenance and/or treatment of these disorders. Importantly, the present evidence demonstrates the necessity of integrating trait cognitive control and threat-level in future theoretical frameworks of anxiety and AB.

Besides threat-level, the time-course of attention is also suggested to be an important factor in the processing of emotional information. In chapter 3, we attempted to assess whether the role of trait voluntary cognitive control is present in late rather than early stages of attention (200 vs 500 ms; Angelidis et al., 2018), as was previously found (Derryberry & Reed, 2002). In our first study, however, AB did not differ between these stages of attention and the role of trait cognitive control was present for both probe-delays (chapter 3; Angelidis et al., 2018). Since AB did not differ between 200 and 500 ms and there is more evidence suggesting that avoidance may already occur in 200 ms (Koster, Crombez, Verschuere, Vanvolsem, & De Houwer, 2007; Mackintosh & Mathews, 2003), in a second study, the same hypothesis was revisited using a 80 ms and 200 ms probe-delay (chapter 4; van Son et al., 2018a). Results showed that self-report trait attentional control moderated threat-related AB in the 200 but not 80 ms delay-condition. Similarly, Bardeen & Daniel (2017) found that trait attentional control moderated the relation between post-traumatic stress symptoms and threat-related AB in later stages of attention. It should be noted that the latter evidence is found in different stages of attention while assessing overt attention with an eye-tracking technique, and therefore direct comparison of the results would not be prudent. The above mentioned evidence supports the notion that trait cognitive control is a higher order cognitive function that regulates attentional emotional responses after initial automatic responses.

The present findings provide further insights in threat-related AB that should be taken into consideration. One research line, for which the findings are likely highly relevant, is Attention Bias Modification (ABM) training. In the last decade, there has been increasing interest in this computerized method which attempts to train attention away from threatening information in order to reduce anxious symptomatology (e.g., MacLeod & Clarke, 2015; for a review, see Mogg & Bradley, 2018). The effectiveness of ABM trainings in reducing anxious symptomatology or even modifying initial threat-related attention has not been as fruitful as it could be expected so far (e.g., Schoorl et al., 2014; for a review, see Cristea, Kok, & Cuijpers, 2015; Cristea, Kok, & Cuijpers, 2017; Mogg & Bradley, 2018; van Bockstaele et al., 2014). Importantly, many studies did not even find initial attention to threat in some anxious individuals (e.g., Water, Bradley, & Mogg, 2014; Mogg & Bradley, 2018). Our findings may partly account for the ineffectiveness of ABM trainings (Angelidis et al., 2018; van Son et al., 2018a; van Son et al., 2018b). To explain, in line with the cognitive-motivational framework (Mogg & Bradley, 1998, 2016, 2018), we found that attention towards HT was observed in resilient individuals with higher trait cognitive control and lower trait anxiety. Taking these findings into account, training attention away from highly arousing threatening stimuli can be harmful as it may alleviate anxious feeling temporarily but may lead to enhancement of anxious symptomatology (e.g., Mogg & Bradley, 1998, 2016; Bardeen & Daniel, 2017). Future research in ABM trainings should take into account the role of trait

cognitive control and threat-level. A recent study showed that an ABM training was effective only for individuals with higher objective cognitive control (Basanovic, Notebaert, Grafton, Hirsch, & Clarke, 2017). The present evidence is also in line with a recent review on ABM trainings underlining the necessity to integrate attentional time-course, threat-appraisal, and trait cognitive control for the development of novel ABM trainings (Mogg & Bradley, 2018). Alternatively, it may be more effective to train cognitive control (e.g., Sari et al., 2015) in order to reduce anxious symptomatology as trait cognitive control is found to be a crucial factor in attentional processing. However, researchers and clinicians should be cautious when attempting to enhance trait cognitive control as it is shown that highly anxious individuals with high trait cognitive control tend to avoid HT stimuli (Angelidis et al., 2018; Bardeen & Daniel, 2017; van Son et al., 2018a; van Son et al., 2018b). Hence, enhancing trait cognitive control in highly anxious individuals may temporarily alleviate anxious feelings but eventually, it may result in maintenance or exacerbation of anxious symptomatology (e.g., Bardeen & Daniel, 2017; Mogg & Bradley, 2016). Perhaps, an intervention that combines training of cognitive control and ABM would be more efficient. An intervention like this would first enhance individuals' ability to control their attention while in a second step, it would train them to orient their attention away from MT (and/or towards HT).

Stress and threat-related attentional bias

In the present thesis (chapters 5 and 6), the effect of acute stress on threat-interference was investigated. As mentioned in the General Introduction, studies commonly assume a similar relationship between trait and state anxiety, and AB to threat. The attentional control theory (Derakshan et al., 2009), for instance, suggests a positive relationship between state anxiety (i.e., stress) and AB. This is mainly extrapolated from evidence related to trait anxiety and might very well be conceptually flawed (as explained in chapter 1). Other theoretical frameworks, however, suggest the unique and interacting role of trait and state anxiety (e.g., Williams, Mathews, and MacLeod, 1996; Mogg & Bradley, 1998). In chapters 3 (Angelidis et al., 2018), as discussed above, it is observed that the relation between trait anxiety and AB is dependent on the threat-level of sitmuli while the role of individual differences in trait cognitive control is underlined. In the present thesis, the direct effect of acute stress on threat-level dependent AB was not investigated. It was found, however, that the effect of hydrocortisone-administration on interference from distinct levels of threat, in a sample of stressed individuals who were vulnerable to such stress, was moderated by trait cognitive control and trait anxiety, supporting again the notion that threat-level, trait cognitive control and trait anxiety are important factors in research related to acute stress and AB. In chapter 5, acute stress resulted in higher interference from negative evaluation words (that could be considered MT) during a WM task with a high cognitive load (Angelidis et al., 2019). This effect was present only in

individuals with higher trait cognitive test anxiety. This further suggests the interacting role of trait and state anxiety on threat-related AB, as previously proposed (Egloff & Hock, 2001; Williams, Mathews, and MacLeod, 1996; Mogg & Bradley, 1998). Moreover, in chapter 6, a main effect of acute stress on interference from negative evaluation-words was found only in one of the congitive tasks, indicating stress-induced reduction of threat-interference, while in chapter 5, there was no main effect (Angelidis et al., 2019). However, it was observed, for the first time, that objectively-assessed trait cognitive control, also in interaction with trait anxiety, moderated the effect of acute stress on interference from negative evaluation words (chapter 6). Specifically, the most resilient individuals with higher trait cognitive control, or also with lower trait anxiety, showed reduced threat-interference. This finding is in line with cognitive theories suggesting the importance of avoiding threat in order to proceed with a task-relevant behaviour (Derakshan et al., 2009; Mogg & Bradley, 1998, 2016). However, it is noteworthy that the findings in chapter 6 suggest stress-induced increase of executive performance at least for individuals with higher cognitive control, indicating that the stress-levels were not high enough to impair performance. This evidence is in line with the inverted U-shaped effect of stress on performance (Arnsten, 2011; Yerkes, 1908) as the resilient participants of this study possibly reached the peak of the apex, showing lower threat-interference. All in all, the current findings in relation to acute stress and threat-related AB clearly suggest the complexity of this relationship and underline the importance of many factors that should be taken into account in future research. Considering that the effects of acute stress on threat-related attentional processing has received ample interest for more than two decades, the complexity of this issue possibly accounts for the relatively limited published reports of main effects. Future reseach should further shed light in this phenomenon by taking into consideration the moderating role of trait anxiety.

Stress, AB and performance

In chapter 5, it was found for the first time that acute stress, in the context of performance anxiety, increased objective interference by negative evaluation words during performance while WM efficiency was impaired. These effects were stronger for individuals with higher trait cognitive test anxiety. The current evidence further supports the theories suggesting that stress impairs performance by directing attention to negative thoughts or stimuli resulting in limited resources for the task at hand (e.g., Derakshan et al., 2009). This is an important first step as this notion was based on studies investigating effects of anxiety either on threat-interference or on performance, while, as mentioned before, most of this evidence was in relation to trait anxiety. There is only one study showing that acute stress simultaneously increased threat-interference and impaired cognitive performance (Coy, O'Brien, Tabaczynski, Northern, & Carels, 2011) however, threat-interference was assessed with the self-report

cognitive interference questionnaire in that study (Sarason, Sarason, Keefe, Hayes, & Shearin, 1986). Disadvantages and potential misinterpretations of the use of a self-report measure for threat-interference are discussed below. Future research should replicate these findings but also further investigate whether objective threat-interference mediates the effects of acute stress on cognitive performance. Moreover, it is important to investigate the effects of acute stress on threat-interference in relation to cognitive demands. In chapter 5, it was found that acute stress increased threat-interference during WM performance only when cognitive demand was high. This is in line with the empirically supported load theory (Lavie, 2010) which suggests that higher cognitive demands limit the available resources of goal-directed cognitive control, resulting in increased emotional interference. However, threat-interference is commonly assessed with simple reaction-time based tasks, such as the emotional Stroop task and the dot-probe task, where cognitive demands are not manipulated. Hence, the investigation of threat-interference during more demanding WM performance in relation to cognitive load would provide further insights in the field of acute stress.

Pharmacological intervention

In chapter 7, we attempted to prevent the effects of acute stress on threat-interference in highly anxious individuals by administering 40 mg of hydrocortisone an hour prior to the stress procedure. It was found that individuals with higher objective or subjective trait cognitive control, also depending on trait anxiety scores, in the hydrocortisone group showed lower interference by highly arousing emotional, threatening and erotic, stimuli. Although, there is accumulating evidence showing that the slow effects of cortisol reduce emotional processing of emotional information (for a review, see Putman & Roelofs, 2011), this is the first evidence showing that the slow effects of hydrocortisone-administration reduces interference from emotional stimuli also under acute stress, when noradrenaline levels are expected to be high. Moreover, in chapter 7, hydrocortisone administration increased state attentional control under acute stress further suggesting that the slow effects of cortisol suppress the processing of emotional information by enhancing cognitive control. It could also be argued that the present effect was not due to enhancement of PFC-mediated cognitive control rather than impaired retrieval of emotional mnemonic structures. The retrieval-hypothesis of glucocorticoids on emotional information processing suggests that glucocorticoids alleviate the emotional response to relevant information by suppressing the retrieval of negative memories (e.g., De Quervain, Aerni, Schelling, & Roozendaal, 2009). The present findings, however, do not support this hypothesis since hydrocortisone did not reduce stress-reactivity in response to the stress manipulation, as previously observed in this context (e.g., Weckesser et al., 2016).

The current evidence is promising for the use of hydrocortisone to prevent the negative effects of acute CPA. However, they are premature and extensive research is needed before considering exploiting this as an intervention. Future research should further investigate the effects of hydrocortisone administration on executive performance using different doses but also using more ecologically valid measurements of performance. Finally, future designs investigating these effects should also include a non-stress control group in order to clearly define which effects of stress are modulated by hydrocortisone.

Objective vs subjective measurements

In the present thesis, objective and subjective measures for trait cognitive control and threat-interference were used. This method was used to identify and suggest the future use of more valid measures that overcome some of the potential disadvantages of self-report measures. Regarding self-report trait attentional control, it was observed that ACS did not consistently associate with expected outcomes. In chapter 4, it was found that ACS related to threat-related AB. However, this evidence was not present in chapter 3 while it was present for TBR in both studies. Moreover, in chapter 6, ACS associated with subjectively-assessed threat-interference while TBR with an objective measure of threat-interference. As mentioned before, the fact that the two self-report measures were associated only between themselves could be attributed to the shared variance by using the same method, also known as common variance phenomenon (Podsakoff, MacKenzie, Lee, Podsakoff, 2003; Richardson, Simmering, & Sturman, 2009). Moreover, ACS is designed to assess trait attentional control but its validity is questionable as it rather indicates individuals' perception of their attentional control, as recently suggested (Quigley et al., 2017). Another study in our lab (unreported data), showed that participants in a stress group, but not in the control group, reported lower scores of ACS at the end of the study and after being fully debriefed, as compared prior to the manipulation, possibly indicating that their perception of their trait attentional control was influenced by their emotional state. ACS consists of 20 items aiming to assess trait attentional control (Derryberry & Reed, 2002). Many studies focusing on the psychometric properties of ACS suggest the exclusion of some items (e.g., Clauss & Bardeen, 2018; Judah, Grant, Mills, & Lechner, 2014). However, ACS is still used in its initial form, as in our studies. Although the evidence for the concurrent validity of ACS is positive, relating to trait/state anxiety, positive/negative affect, depressive and PTSD symptomatology and more (e.g., Angelidis et al., 2016, 2018; Bardeen & Daniel, 2017; Derryberry & Reed, 2002; Putman et al., 2010a; Reinholdt-Dunne, Mogg, & Bradley, 2009; Schoorl et al., 2014), it should be noted that all these constructs were assessed with self-report measures. However, the evidence for convergent-related validity of the ACS is limited (Claus & Bardeen, 2018) since there is no consistent relation between ACS and task-based WM performance

(e.g., Angelidis et al., submitted; Quigley et al., 2017; but see, Judah et al., 2014). Therefore, even though ACS has been the main and very useful self-report tool in the investigation of trait attentional control, future research should develop a new scale, in a better attempt to assess specific functions of executive control. Moreover, a possible improvement would be to assess attentional abilities in a specific context, such as academic or occupational environment.

Regarding self-report threat-interference, the cognitive interference scale (CIQ) is designed to assess cognitive interference during performance (Sarason, Sarason, Keefe, Hayes & Shearin, 1986). However, as it is mentioned above, the items assess how often thoughts occurred during performance and it is only assumed that these thoughts interfered with performance. In chapter 6, findings suggest that acute stress resulted in enhanced objective executive control over threatening information and higher self-report threat-interference for individuals with higher trait cognitive control. This finding is quite paradoxical but it is probably explained by the expected response of participants to indicate more negative concerns during performance after an acute stressor. However, this does not indicate that the stress levels were high enough to actually interfere with performance as it is automatically assumed with the CIQ. Hence, future research should be cautious with the use of CIQ as a measure for threat-interference while objective measurements would be more informative.

Limitations

Several limitations have already been discussed in relation to individual studies (see each empirical chapter) but also in relation to specific topics discussed in the current chapter. There are, however, some general limitations that need to be further considered. First, all of our studies were conducted in healthy samples. Even though individual differences in trait anxiety were investigated and the study in chapter 7 was conducted in highly anxious individuals, the anxiety levels were probably still limited. Anxious psychopathology is characterized by reduced cognitive control and disrupted emotional processing (e.g., Etkin & Wager, 2007; Lanius, et al., 2010; Schoorl et al., 2014). It would therefore be very informative to study emotional processing in relation to threat-level, cognitive control and acute stress in individuals with anxiety disorders. Second, most of the studies (chapters 2, 5, 6, and 7) were conducted on female samples. The use of hormonal contraception methods as well as hormonal cycle are known to affect stress-evoked cortisol responses, and emotional state and processing (e.g., Hamstra et al., 2015; Hamstra, et al., 2016; Kirschbaum, Pirke, & Hellhammer, 1993). Moreover, females are suggested to be more anxious than men (e.g., Mano, Gibler, Mano, & Beckmann, 2018; McDonald, 2001; Putwain, 2007; Putwain & Daly, 2014). This may be, however, of more clinical relevance since (healthy and clinically) anxious individuals are more susceptible to emotional challenges. Moreover, by including only females, there is a better control of endogenous hormonal variability. Finally, the effect of acute stress on

executive performance was assessed using laboratory psychosocial stress-induction procedures. These methods are advantegeous for investigating specific aspects of this relationship in a controlled environment. However, there are inherent inevitable flaws. For instance, even though "effective" psychosocial stress tests are based on creating a feeling of uncontrollability under social evaluation, it is apparent that this is an artificial situation that does not have a real impact on individuals' lives. As a result, these methods, compared to real life stressors, are not perfectly suitable as it is harder to affect resilient people. One of the main difficulties in observing a main effect of acute stress on executive performance is the inverted U-shaped effect of stress on performance, as it was also supported by evidence in chapter 6. This non-linear relationship between stress and performance results in increased variability, as resilient individuals may show enhanced performance while vulnerable participants may perform worse.

General conclusions

All in all, the current findings contribute to the understanding of the relationship between anxiety, cognitive control, and executive cognitive performance, especially attentional processing of emotional information. It can be concluded that spontaneous frontal TBR is possibly a reliable marker for trait cognitive control, also over emotional information. Threat-level and the time-course of attention are important aspects in the investigation of cognitive affect regulation and should be taken into account in future research. Cognitive control, also in interaction with trait anxiety, is a crucial factor on the investigation of threat-related attentional bias but also on the effects acute stress on executive performance. Moreover, cognitive load seems to play an important role on the effects of stress on threat-interference during WM performance. The present findings also suggest that we have developed a proper method (combining the L-PAST with the emotional *n*-back task) to investigate the effects of acute performance anxiety on threat-interference during WM performance and on WM performance. Moreover, hydrocortisone-administration may be an effective intervention to prevent the negative effects of acute stress on processing of emotional information in highly anxious females. The current findings provide a further understanding of the role of trait cognitive control, and frontal EEG TBR, in the relationship between anxiety and attentional processing of emotional information. Although we believe that we have developed a good conceptual and methodological approach for the current constructs and their relationships, future research should replicate and further investigate the relations between cognitive control, anxiety, and executive performance.