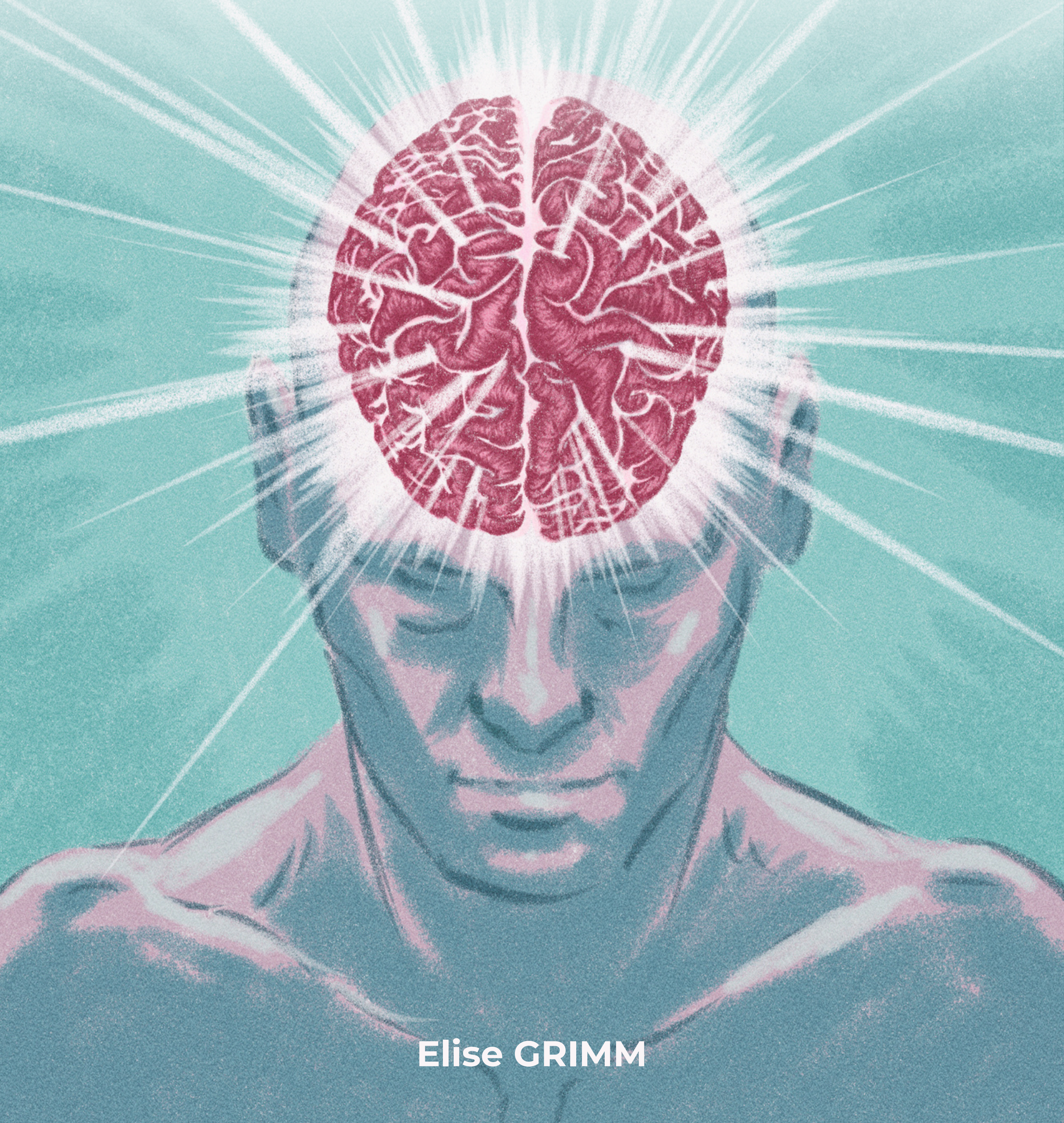
EXECUTIVE FUNCTIONING AS A DETERMINANT OF ACUTE STRESS RESPONSES

Investigating the Role of Cognitive Appraisals and Affect Regulation



Elise GRIMM

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Abstract

Exposure to acute stressors is considered important for bolstering resilience. However, sustained stress responses to such events can have detrimental long-term effects on both mental and physical health. Research frameworks suggest that executive functioning may be implicated in protecting against excessive stress responses, but research testing this assumption remains limited. The aim of this thesis was two-fold: first, to evaluate the protective role of executive functioning with respect to stress anticipation, reactivity, and recovery; and second, to explore the mediating roles of cognitive and behavioral factors in this association. We found evidence for better executive functioning facets predicting lower subjective and physiological stress responses in ecological settings (examination stress), laboratory settings (acute induced stressor), and in daily life (daily stressors). Given the relevance of cognitive flexibility, we sought to extend these findings to affective flexibility. We discuss the theoretical, methodological, and practical implications for cognitive flexibility and stress regulation.

Résumé

L'exposition aux événements stressants est essentielle pour renforcer la résilience chez tout individu. Cependant, des réponses de stress répétées et soutenues peuvent avoir des effets néfastes à long terme sur la santé mentale et physique. Les recherches suggèrent que les fonctions exécutives protègeraient contre des réponses de stress excessives, mais cette hypothèse reste peu testée. Cette thèse vise à combler cette lacune en visant deux objectifs : premièrement, évaluer le rôle protecteur des fonctions exécutives dans l'anticipation, la réactivité et la récupération face au stress aigu ; ensuite, explorer les rôles médiateurs des facteurs cognitifs et comportementaux dans cette relation. Nos résultats révèlent que de meilleures fonctions exécutives sont associées à des réponses de stress subjectives et physiologiques plus faibles dans divers contextes, qu'il s'agisse du stress lié aux examens, du stress induit en laboratoire ou des événements stressants du quotidien. La flexibilité cognitive s'étant révélée être un prédicteur significatif des réponses au stress et des stratégies de régulation de l'humeur, nous avons également cherché à comprendre le rôle de la flexibilité affective. Nous discutons des implications théoriques, méthodologiques et pratiques de la flexibilité cognitive pour la régulation du stress, en soulignant son rôle déterminant et en offrant des perspectives pour de futures recherches et interventions.

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Section 1.

General Introduction

Chapter 1.

Theoretical background

1.1. Stress

In the 2023 AXA Mind Health Report (2023), almost 25% of Belgian respondents reported extremely severe stress symptoms, on a scale rated from normal, mild, moderate, severe, and extremely severe. In other countries, one in 14 adults in the United Kingdom reported feeling stressed every day (CIPHR, 2021), while The Stress in America 2023 survey (APA, 2023) revealed that 24% of adults rated their average stress between eight and ten on a scale of 1 (“little to no stress”) to 10 (“a great deal of stress”). Sustained and repeated experiences of stress is predictive of poor mental (e.g., anxiety, depression) and physical (e.g., cancer, heart disease) outcomes (Fink, 2010; Godoy et al., 2018; Quick et al., 2014). In November 2023, the prevalence of anxiety and depression – both stress-related disorders – rose to 20% and 18% in Belgium, respectively (Sciensano, 2023). Given the considerable burden of the effects of stress, it is imperative to prioritize research aimed at identifying adaptable protective factors. In this section, I define the main phases of the stress responses and outline the different designs and measures for stress in psychology research.

Anticipation, Reactivity, and Recovery to Stressors

Through his experiments with rats, Hans Selye was the first to identify the "general adaptation syndrome," later termed the "stress response" (Selye, 1946, 1950). The response he observed comprised three main components: enlarged adrenal glands, lymph node and thymic atrophy, and gastric erosions/ulcers (Selye, 1946). Selye’s stress response focused on the adrenal cortex and the release of glucocorticoids (Szabo et al., 2012), that we now understand are central to generating responses when faced with stressful events.

Acute stress must be distinguished from chronic stress. The former is a temporary stress response instigated in relation to a specific event (e.g., a dispute with a family member, traffic, work demands), that diminishes after a short period (Wright et al., 2019). Chronic stress refers to the accumulation of prolonged and/or repeated exposure to high intensity stressor(s) over longer time periods (e.g., being a caregiver, occupational stress), with effects persisting after the stressor (Rohleder, 2019). The current PhD thesis focuses on how stress responses develop with respect to the former only.

Stress *reactivity* is defined by the degree of physiological and subjective (immediate or delayed) reactions observed when an individual faces a stressful situation. Immediate physiological responses involve the activation of the sympathetic-adrenal-medullary (SAM) axis, releasing epinephrine, norepinephrine, and alpha-amylase while increasing heart rate and blood pressure (Nater & Rohleder, 2009). The later response involves cortisol release (the main glucocorticoid stress hormone) by the Hypothalamic-Pituitary-Adrenal (HPA) axis. The *recovery* phase, following stress reactivity, represents the residual physiological and psychological activation that persists after the stressor is terminated or eliminated (Williams et al., 2009). It represents the degree to which the autonomic responses decrease once the stressor is no longer present, allowing for the body to return to homeostasis.

Anticipatory stress is a distinct phase from stress reactivity. Researchers have shown that anticipating potentially stressful situations can elicit reactions similar to those present when we actually experience the situation, including negative mood (Feldman et al., 2004), cardiovascular activation (Waugh et al., 2010), or even greater cortisol release (Mikolajczak et al., 2008). Using psychosocial tasks such as the Trier Social Stress Test (TSST; Kirschbaum et al., 1993), significant activation of the HPA axis can be observed before actual exposure to the situation. Other studies have shown that this anticipatory response can also extend over a longer period of time, spanning hours or even days (Preuß et al., 2010; Rohleder et al., 2007). It is important to note that these three responses are inherently adaptive and protective (McEwen, 2007). They allow for the generation of the "fight-or-flight" response, providing oneself with sufficient energy to face the stressor and/or to cope with it appropriately. Stress researchers have attempted to capture stress anticipation, reactivity, and recovery using diverse study designs.

Stress Designs and Measures

As a dynamic process, acute stress must be considered under a variety of conditions. Methodological designs implemented to capture such acute stress include validated self-reported questionnaires, controlled acute stress inductions in the laboratory, and ecological momentary assessment designs (Dorsey et al., 2022). Self-report measures of stress involve sets of questions aimed at assessing a wide range of symptoms induced by one's exposure to a stressor. These questionnaires can provide important information not only about self-perceived feelings of stress, but also about the appraisal of stressful events and the strategies implemented to manage them. Moreover, they can provide key information to understand the physiological recordings measured in parallel (Dorsey et al., 2022). Finally, they also help researchers understand common stressors that naturally occur in different individuals.

In the laboratory, a variety of controlled stress inductions have been developed (for reviews, please see Ernst et al., 2023; Skoluda et al., 2015). Some of these involve a psychosocial task (Trier Social Stress Test, Kirschbaum et al., 1993), a physical test (Cold Pressure Test, Hines, 1932), or a combination of both (e.g., Maastricht Acute Stress Test, Smeets et al., 2012). Elements of an effective acute stress inductions include the presence of social-evaluative threat, novelty, uncontrollability, and motivated performance (Dickerson & Kemeny, 2004). This approach offers significant advantages, including the possibility to standardize stress exposure and environmental factors across all participants. Laboratory stressors are particularly suitable for studying responses to different types of controlled stressors, for capturing precise phases of the stress experience, and for investigating how between-subject variables and easily manipulable variables moderate stress responses.

Finally, ecological momentary assessments (EMA) promote the study of stressors as they occur, dynamically, on a moment-to-moment basis. This methodology allows for the measure of both exposure to predictable challenges (e.g., commuting) and unpredictable events (e.g., unexpected work deadline; Piazza et al., 2013). Further, one can capture the affective, cognitive, and behavioral responses to these stressors as they unfold in real time. Thus, EMA allows stress researchers to capture the dynamic interaction between exposure to stressful events and subsequent responses, under ecological settings. The advantage of EMA lies in the ability to study the within-subject associations between stressors experienced in daily life and subsequent stress responses. They also allow researchers to explore how variables that vary greatly throughout daily life, and are difficult to manipulate in laboratory settings, moderate these effects. Given that these approaches provide different angles to the study of acute stress, all three were incorporated in the current thesis.

As we have seen, stress responses can stem from a variety of situations, and vary depending on other individual factors. Identifying these underlying mechanisms and protective factors have become primordial for researchers seeking to promote resilience and reduce long-term negative consequences for one's health. This PhD thesis is interested in the extent to which executive functioning may act as a buffer against excessive stress responses and may aid in promoting optimal stress regulation.

1.2. Executive functioning

Definition

Executive functioning constitutes a higher-order neurocognitive system that enables oneself to organize one's actions, to implement adaptive behaviors in line with one's goals, and to adapt to an ever-changing environment (Jurado & Rosselli, 2007). There is well-known lack of consensus regarding the conceptualization of executive functioning (for a review, see Baggetta & Alexander, 2016). Miyake and colleagues' (2000; Friedman et al., 2008; Friedman & Miyake, 2017) unity-diversity framework of executive functioning was selected for the current thesis (Figure 1). They identify three interrelated, but partially distinct, facets. Firstly, the inhibition of automatic or prepotent responses explains no variance beyond a common component of executive functioning. Inhibition capabilities involve preventing responses, thoughts, and emotions that were previously relevant but may be inappropriate for the current task (Miyake & Friedman, 2012). Two additional processes— shifting mental sets and updating information in working memory account for unique variance but also rely on this common factor. Set shifting – otherwise referred to as cognitive flexibility or switching (Diamond, 2013) – enables individuals to switch from one goal, idea, or perspective to another. Updating working memory allows individuals to monitor incoming information in working memory and to discard content that is no longer relevant to the current task (Miyake & Friedman, 2012). Traditionally, the prefrontal cortex has been identified as the main brain area involved in executive functioning. It is now understood that executive functioning depends on the integrity of complex brain networks and how these connect with one another (e.g., Suchy, 2009).

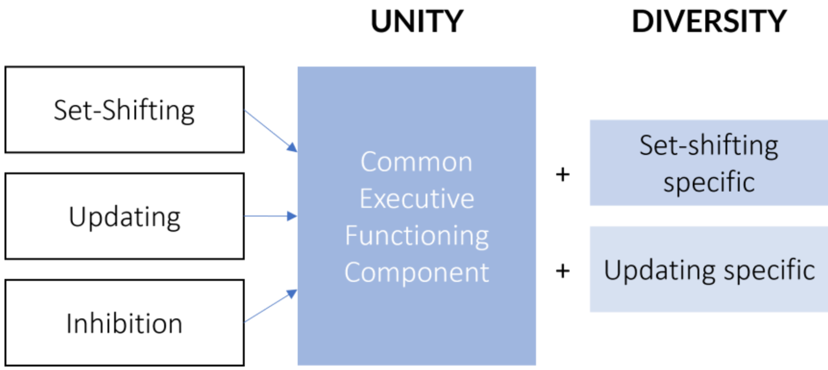

Figure 1. Schematic representation of unity and diversity of the three executive functions

Note. Figure adapted from Miyake & Friedman (2012) and Morales et al. (2016).

It is also important to consider the role of working memory capacity, given that these executive functioning operations occur within it. Working memory capacity is the system responsible for actively maintaining and manipulating information over short time periods (McCabe et al., 2010). We differentiate executive functioning (i.e., inhibition, cognitive flexibility, updating) from working memory capacity, all the while acknowledging that they share commonalities (e.g., McCabe et al., 2010; Miyake & Shah, 1999; Shipstead et al., 2014). The link between updating and working memory capacity is clearly strong (Frischkorn et al., 2022; Schmiedek et al., 2009) but they capture shared – but not redundant – variance. Although some researchers mention updating and working memory capacity interchangeably, we believe it is crucial to separate them. A key strength of this PhD thesis is the independent consideration of these facets and their individual influence for stress responses.

The role of executive functioning in stress responses

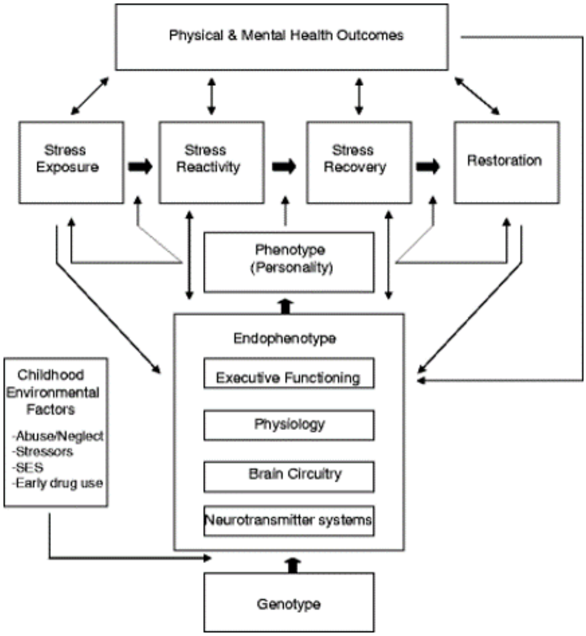

Figure 2. Schematic representing levels of individual differences in executive functioning and their relation to stress responses

Note. Figure copied from Williams et al. (2009), with permission of the Oxford University Press.

An important section of the stress-cognition literature has focused on the deleterious– though not always consistent – effects of stress upon different executive functioning facets (for reviews, see Plieger & Reuter, 2020; Shields, 2020; Shields et al., 2016). In contrast, executive functioning may also protect individuals against excessive stress responses. Williams and colleagues (2009) originally proposed an integrative and developmental model of individual differences in executive functioning and stress regulation (Figure 2). According to their model, individual differences in executive functioning could be observed at the genetic, neuroanatomical, physiological, cognitive, and personality levels. They acknowledged that evidence suggests a reciprocal relationship between executive functioning and stress, with executive functioning influencing vulnerability to stress responses and stress further impacting these facets in return. In their model, the authors recognize that while modest stress exposure may promote greater resilience, severe stress may increase vulnerability. Individuals with poorer executive functioning may be more susceptible to the exposure to major life events or daily hassles and exhibit enhanced physiological reactivity and prolonged stress activation (i.e., delayed recovery). This may also lead to sleep disruption and further impairments in executive functioning. This negative cycle of stress and executive functioning difficulties may contribute to long-term mental and physical health outcomes. Additionally, chronic illness and psychopathology can exacerbate executive functioning deficits.

To address this theoretical model and understand the suggested phenomenon, Chapter 2 of this thesis presents a systematic review and meta-analysis examining the evidence for the proposed association between executive functioning and acute stress. Chapters 3, 4, and 5 extend this investigation by evaluating the relationship between these constructs across various methodological contexts. Beyond the direct relationship between the two constructs, important empirical findings and theoretical models also suggest that cognitive and behavioral stress responses, namely appraisal and affect regulation, may mediate the association between the two.

1.3. Appraisal and affect regulation

Definition of appraisals

According to the Transactional Model of Stress and Coping (Lazarus & Folkman, 1984a), stress responses stem from a discrepancy between how one perceives the demands of a situation (primary appraisals) and the available coping resources (secondary appraisals). Initially, individuals evaluate whether an event is relevant to their well-being and whether its outcome is important for them (centrality). Subsequently, they assess whether the event is neutral, positive, or negative. In the case of negativity, further evaluations may categorize it as harmful, threatening, or challenging (Carpenter, 2016). Simultaneously, individuals also evaluate the range of possible actions, their coping resources, and the degree of control over the stressor. Therefore, stress arises from the interaction of these appraisals, which are dynamic processes (Gaab et al., 2005; Lazarus & Folkman, 1984a). For a longer discussion on primary and secondary appraisal in stress research, I invite readers to consult **Appendix A**. It presents two studies conducted to validate the Stress Appraisal Measure in the French language and extensively discusses the relevance of appraisal and its measurement in stress research (Grimm et al., 2024; Peacock & Wong, 1990). Appraisals play an important role in shaping responses to stressors and influence how individuals may choose coping strategies to face the event.

Definition of affect regulation

Recent approaches to stress and resilience advocate for the use of the term “affect” to refer to “any response to an internal or external stimulus that involves valuation (e.g., “Is this good for me or bad for me?”) (Troy et al., 2023). This comprehensive term covers stress responses, emotions, and moods (e.g., feeling grumpy, down; Gross, 2015). Resilience can be defined in three ways: as a trait, a process, and an outcome (Arnold et al., 2023; Troy et al., 2023). Firstly, it can be viewed as a stable trait that exists regardless of adversity, such as a predisposition for adapting to environmental change. Secondly, it can be seen as a process involving various capacities and resources deployed in response to stressful events, including social and psychological aspects like coping strategies and emotion regulation. Finally, resilience can manifest itself an outcome, such as sustained or improved functioning following adversity.

Historically, work on affect regulation has been divided into two main research domains: the emotion regulation approach and the stress and coping approach. While these strategies will be detailed in subsequent articles of this PhD thesis, I offer an overview of both research approaches and discuss their integration into stress research. Given the scope of this PhD thesis, I recommend referring to Troy et al. (2023) for a comprehensive literature review of affect regulation and to Trudel-Fitzgerald et al. (2023) for a scoping review highlighting the many similarities between the two constructs and their measures.

Emotion regulation

Emotion regulation refers to one's capacity to manage one's emotions, automatically or voluntarily, to maintain emotional stability and accomplish one's objectives (Aldao et al., 2015). Gross's (2015) model of emotion regulation is based on a four-stage process (Figure 3). Emotion regulation strategies can be implemented at each stage of the emotion process (Gross, 2015). At the first stage, situation selection involves deliberately choosing actions that will increase or decrease the likelihood of encountering situations expected to elicit favorable or unfavorable emotions. *Situation modification* involves directly intervening in a situation to alter its emotional impact. At the second stage, *attentional deployment,* such as distraction, entails deliberately focusing one's attention on specific stimuli to influence one's emotional response. *Cognitive change,* such as reappraisal, involves adjusting one's appraisal of a situation to change its emotional impact. Finally, *response modulation*, such as through the use of alcohol or cigarettes, involves actively influencing the experiential, behavioral, or physiological aspects of an emotional response after the emotion has already developed.

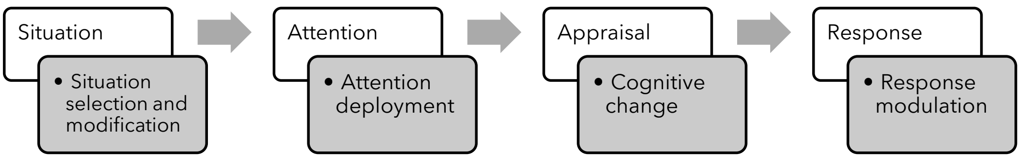

Figure 3. Emotion Regulation Process Model adapted from Gross (2015)

However, emotion regulation is not limited to emotions, and can also be implemented with respect to stress responses. Given that stress is divided into different phases (e.g., stress anticipation, reactivity, and recovery), the processes involved in emotion regulation are thought to vary at each stage (for a full review, please refer to Flores-Kanter et al., 2021). The processes of emotion regulation are dependent on two main brain systems. System 1 (bottom-up) operates automatically in reaction to stressors (Panel B in Figure 4), while System 2 (top-down) involves more complex cognitive processes and requires deliberate effort (Panel C in Figure 4). The interplay between these systems can lead to either an increase or decrease of the stress response. For example, greater involvement of top-down processes after exposure to the stressor is associated with better recovery from stress. Among the emotion regulation strategies classified as requiring top-down activation, lie reappraisal, acceptance, and focusing on plans. Bottom-up processes include catastrophizing and negative repetitive thinking.

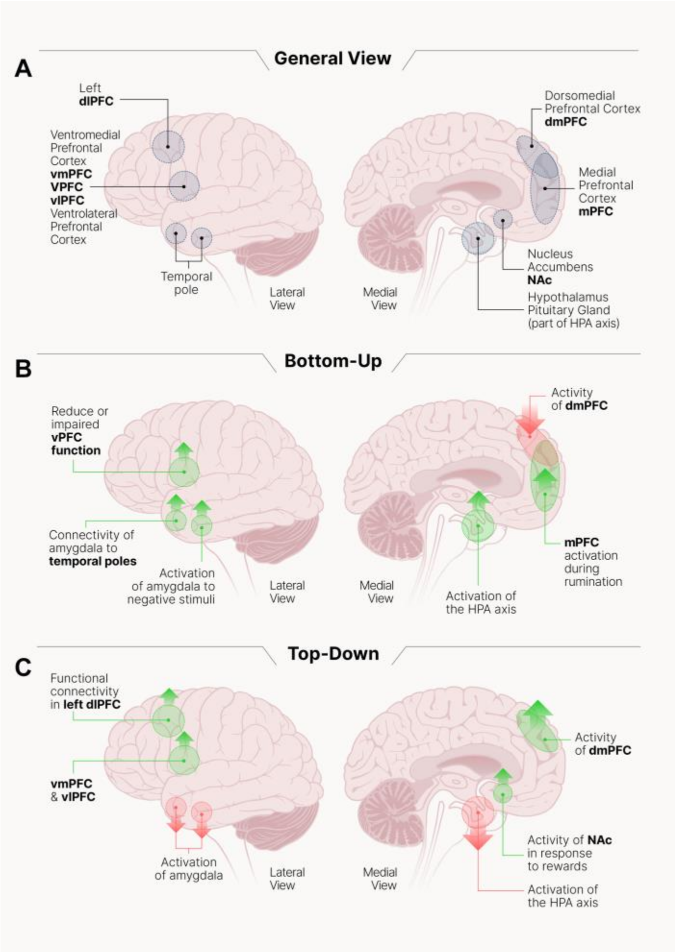

Figure 4. Diagram depicting brain structures involved in generating and regulating emotions

Note. Figure copied from Flores-Kanter et al. (2021). Permission from Elsevier not required for this non-commercial use.

Stress and coping

Psychological stress, as conceptualized by Lazarus (1966; Lazarus & Folkman, 1984, 1987), involves a dynamic interaction between an individual and their environment, otherwise referred to as a "transaction". Under this framework, stress occurs when demands exceed available resources. As mentioned previously, individuals can appraise the stressful situation as harmful or threatening, or alternatively, as a challenge. The choice of coping strategies depends on the selected appraisal. Coping strategies have been defined as voluntary and conscious efforts made by the individual to regulate their emotions, thoughts, behavior, physiological reactions, and environment in response to stressful events or circumstances (Compas et al., 2001).

In contrast to emotion regulation research, the coping approach often explores both psychological (e.g., affective experience) and biological (e.g., immune function, hormones) mechanisms influencing resilience (Epel et al., 1998). It has also been developed to measure real-life coping strategies, with an emphasis on naturalistic studies when faced with specific stressors (e.g., chronic illnesses; Troy et al., 2023). This has led to the development of a number of coping questionnaires (for a review, see Trudel-Fitzgerald et al., 2023), most of which measure dispositional ways of dealing with stressful situations.

Bridging these theories

The Affect Regulation Framework (Troy et al., 2023) argues that both approaches agree on the idea that individuals rarely allow affect to simply happen. When faced with adversity, individuals will often implement strategies to regulate their affect (Compas et al., 2017). Bridging the two theories together, the new framework proposes three key features. First, they maintain the four different types of emotion regulation strategies, in which they incorporate those initially mentioned only for coping (Troy et al., 2023). Second, they argue that rather than having one specific outcome, affect strategies may have significant effects for affective experiences (e.g., positive or negative affect), affective behavior, autonomic physiology (e.g., heart rate variability, cortisol responses), and social processes (e.g., social support, closeness, etc.; for a review, see Troy et al., 2023). Finally, the third characteristic is the importance of context. They propose that that the implementation of affect regulation strategies, their consequences, and the relationship between the strategies and resilience are highly dependent on the context (e.g., characteristics of the adverse event such as intensity and duration). By allowing individuals to actively modify their responses to stressful events, affect regulation represents an important mechanism for steering their trajectory towards or away from resilience.

A brief mention of repetitive negative thinking

Among various affect regulation strategies, repetitive negative thinking may play a significant role in exacerbating stress. These are recurrent, persistent, and/or uncontrollable thoughts about negative material (Segerstrom et al., 2000, 2003). This overarching variable includes both rumination (repetitive thoughts focused on the past, often about negative feelings) and worry (repetitive and uncontrollable thoughts about potentially negative future events). Often identified as key transdiagnostic processes in the domain of clinical disorders (Watkins & Roberts, 2020), it has also been identified as a key predicting factor of stress responses and, specifically, their prolongation over time.

The Perseverative Cognition Hypothesis (Brosschot et al., 2006; Ottaviani et al., 2016) suggests that, following a stressor, the occurrence of rumination and/or worry prolongs the circulation of stress hormones, such as cortisol, in the body. Brosschot and colleagues (2006) suggest that this can lead to sustained negative effects on psychological and somatic outcomes, leading potentially to glucocorticoid resistance and significant health effects (Verkuil et al., 2010). In a meta-analysis, both trait and state repetitive negative thinking were significantly associated with physiological activation across multiple biological systems, including autonomic, cardiovascular, and endocrinological systems (Ottaviani et al., 2016). In a similar vein, anticipatory repetitive negative thinking ahead of stressors can also maintain sustained stress responses ahead of actual stressor exposure (Kramer et al., 2021). Therefore, beyond general affect regulation, repetitive negative thinking has been identified as an important mechanism for stress regulation, warranting its distinct consideration in several articles of the current PhD thesis.

The role of executive functioning for appraisals and affect regulation

Executive functioning and successful emotion regulation are conceptually linked as they both involve goal-directed actions in changing environments. Furthermore, neuroimaging data has consistently identified a frontoparietal network supporting both constructs (for a review, see Pruessner et al., 2020). The last decade has brought considerable new knowledge regarding the links between executive functioning, as studied in the field of neuropsychology and neuroscience, with self-regulation, stemming from the domain of social psychology and personality. Hofmann and colleagues (2012) proposed that all facets of executive functioning played an important role for regulating emotional experiences and for an individual's self-regulatory goal pursuits. They suggest that set-shifting is involved in flexible switching between different methods that serve the same goal, as well as between multiple goals. Inhibition is thought to be implicated in actively inhibiting impulses and habitual behaviors that are not aligned with one’s goals. Working memory capacity is involved in (a) actively representing one's goals and standards, (b) exerting top-down control of attention towards goal-relevant information and away from distracting stimuli, (c) shielding goals and standards from interference, (d) suppressing ruminative thoughts that may hinder progress, and (e) regulate unwanted emotions, desires, and cravings to maintain focus on their objectives (for the full review, see Hofmann et al., 2012).

Building on this idea, other research teams reviewed evidence for executive functioning playing a role in emotions and emotion regulation, specifically (Schmeichel & Tang, 2015). Set-shifting is theorized to be implicated in flexibly adjusting emotional responses and behaviors when facing changing contexts and stimuli. Inhibition is thought to enable individuals to override initial – and perhaps maladaptive or unsuccessful - emotion responses and regulatory strategies. Updating may allow individuals to store and manipulate contextual information pertinent to emotional responses and to maintain current relevant goals (i.e., either linked to the situation or to emotion regulation) in working memory. The results of the review identify working memory capacity as the most significant, reliable predictor of greater success in expressive suppression, cognitive reappraisal, and coping with daily stressors. While there was some evidence for cognitive flexibility and inhibition, it remained scarce. It is important to note that this review did not distinguish between working memory and updating tasks, grouping them together under this common term. The authors nonetheless emphasized the importance of separating the effects of the distinct facets of executive functioning for emotion regulation.

A number of neurocognitive models have been proposed to explain the underlying cognitive mechanisms to rumination (Wong et al., 2023). One such model, the H-EX-A-GO-N model (Habit development, EXecutive control, Abstract processing, GOal discrepancies, Negative bias; Watkins & Roberts, 2020), suggests that effective executive functioning is crucial for suppressing or discarding irrelevant information from working memory. This model posits two key processes: the first involves monitoring, shifting, updating, or discarding irrelevant information or thoughts from working memory to alleviate mood. The second highlights how facets of executive functioning, such as inhibition, can override habitual repetitive negative thinking tendencies. An increase in negative thoughts may result from the persistence of irrelevant negative thoughts and a reduced ability to override habitual rumination under stress (Watkins & Roberts, 2020). Supporting this theory, two meta-analyses have reported significant correlations between executive functioning (inhibition, flexibility, and updating) and rumination (Vălenaş & Szentágotai-Tătar, 2017; Yang et al., 2017). Additionally, longitudinal studies have shown that deficits in executive functioning can predict increased rumination over time, both in the short term (specifically inhibition; De Lissnyder et al., 2012) and over an extended period (i.e., spanning eight days; Ng et al., 2022).

A recent model incorporating executive functioning, appraisal, affect regulation, and stress responses is Crum and colleagues' (2020) Stress Optimization model (Figure 5). They argue that the experience of stress does not necessarily have to be “bad”. They adapt Gross’s (2015) model of emotion regulation to show how individuals may benefit from stressful situations. The authors argue that adopting the specific mindset of a positive valuation of stress can have a significant impact on how one might experience it affectively, physiologically, and behaviorally.

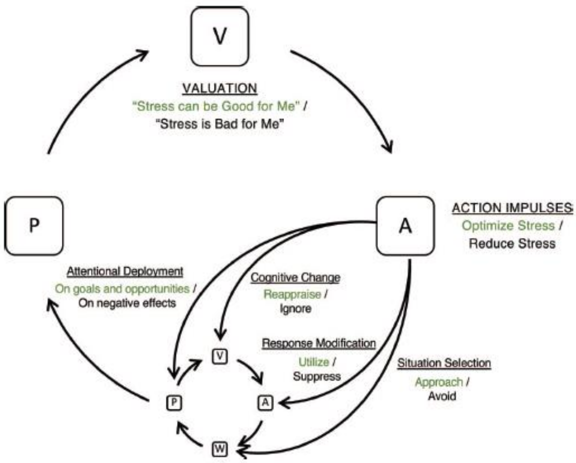

Figure 5. Stress Optimization Model

Note. Figure copied from Crum and colleagues (2020), with permission of the American Psychological Association. A = Action impulses following the valuation; P = Perceptions of what the valuation system has focused on; V = Valuation of the event; W = Internal or external World.

They propose that appraising a stressful situation – and its associated responses – as a beneficial experience should lead to more adaptive action impulses and affect regulation strategies. These include adopting an approach experience to the stressful event, reappraising the event, using or upregulating one's affect to achieve one's goals, and deploying one's attention on the goals and opportunities that facing this situation could bring for oneself. Following from previous models showing the implication of executive functioning for affect regulation, it is proposed here that the flexible deployment of attention from negative affect towards more adaptive goal-related information could help individuals face stressful situations aligned with their values.

1.4. Thesis objectives

This project explores the protective role of executive functioning in the experience of acute stress. It aligns within recent theoretical frameworks suggesting that executive functioning may represent a protective factor against excessive and sustained stress responses. Furthermore, it seeks to address limitations observed in previous studies by considering the operationalization of executive functioning, multiple stress responses, a variety of methodological contexts, and cognitive and behavioral mediating variables.

1. Operationalization of executive functioning: Previous studies have focused on applying a global index of executive functioning, omitting the separate effects of individual facets. This project examines the unique effect of cognitive flexibility, inhibition, updating, and working memory capacity.

2. Stress responses: The combined use of physiological measures (electrodermal activity, blood pressure, heart rate variability) and self-reported measures (perceived stress) provides diverse and complementary data on stress responses, including anticipation, reactivity, and recovery.
3. Variety of methodological contexts: The PhD project investigates stress responses in both controlled (laboratory) and ecological (everyday life) contexts to ensure a comprehensive understanding of the association, as well as its generalization across different settings.
4. Cognitive and behavioral mediating variables: The project also examines the role of appraisals and affect regulation strategies (including repetitive negative thinking) within this association. Figure 6 outlines the theoretical framework behind this thesis.

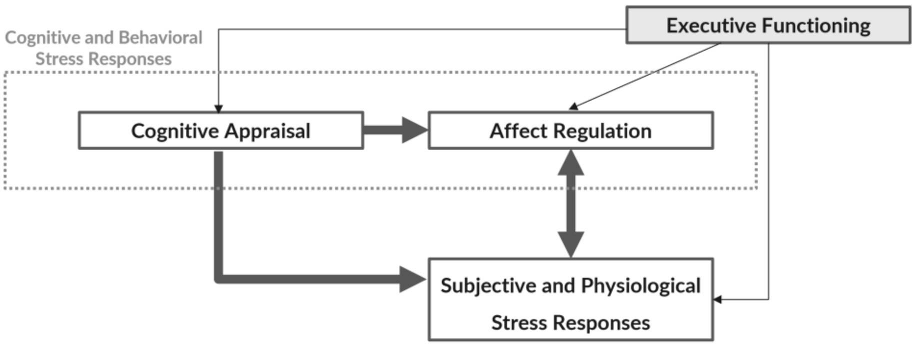

Figure 6. PhD Theoretical Framework

Therefore, the aims of this thesis are two-fold:

1. To investigate the protective role of different executive functioning facets with respect to stress responses.
2. To explore the extent to which cognitive and behavioral processes are implicated in the association between executive functioning and stress responses.

To investigate these aims, the current thesis is divided into three sections. Within the General Introduction, Chapter 2 presents the results of a systematic literature review and meta-analysis examining the role of executive functioning as a protective factor for acute stress in the laboratory.

Section 2 presents the results of three studies investigating the role of different executive functioning facets in stress responses across differing contexts non-clinical samples of adult participants. In Chapter 3, executive functioning tasks were administered ahead of university examinations, and we measured anticipatory stress, appraisals, repetitive negative thinking, and coping strategies implemented ahead of the impending examinations (N = 133). Appendix A presents the results of validation efforts conducted for the French version of the Stress Appraisal Measure that was completed by participants in Chapter 3. It details the Exploratory Factor Analysis conducted on a sample of 425 participants, and a subsequent Confirmation Factor Analysis conducted on a second sample of 308 participants. Chapter 4 delves into subjective and physiological anticipation, reactivity, and recovery to an acute stressor induced in the laboratory (N = 138). We additionally explore the mediating roles of stressor appraisals, different modes of repetitive thinking (abstract, repetitive, and creative), as well as emotion regulation strategies implemented during the stressor instructions and task. Chapter 5 describes the results of an ecological momentary assessment study investigating reactivity and recovery in daily life (N = 120). We further account for appraisals and affect regulation strategies employed to deal with stressors as they occur on a moment-to-moment basis.

Section 3 questions the role of affective material when measuring cognitive flexibility. It is composed of two studies exploring whether the effect of cognitive flexibility observed in previous studies can be replicated when individuals must treat emotional material (Chapter 6). In Study 1, the design strives to replicate Chapter 4, with participants completing an affective flexibility task before an acute stressor (Study 1, N = 130). Study 2 replicates Chapter 3, as the same affective flexibility task is completed ahead of university examinations (Study 2, N = 123).

In the General Discussion, I discuss the theoretical and methodological implications of the different findings, including the consideration of executive functioning – cognitive and affective flexibility, particularly – for stress regulation. I insist on the importance of accounting for different types of executive functions, as well as stress responses and measures. Finally, I outline general implications, limitations, and research perspectives.

Chapter 2.

Executive Functioning as a Predictor of Physiological and Subjective Acute Stress Responses in Non-Clinical Adult Populations: A Systematic Literature Review and Meta-Analysis

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The goal of this systematic review and meta-analysis was to evaluate whether executive functioning predicts subsequent acute stress responses. A systematic search (conducted between May 22nd and 30th, 2019; updated on April 4th, 2020) on Cochrane, OpenGray, Proquest Dissertations and Thesis Global, PsycInfo, Pubmed, Scopus, and Web of Science revealed 27 correlational and five interventional studies. For quality appraisal, we used the BIOCROSS Tool, the Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies, and the Revised Cochrane Risk-of-bias Tool for Randomized Trials. Attentional control was most consistently associated with acute stress. A robust variation estimation meta-analysis, conducted when sufficient data was available, revealed a small, significant, and negative correlation between higher working memory and subsequent lower cortisol reactivity (r = .09, p = .025, 95 % *CI* [0.15, 0.02]). These results highlight the role of executive functioning for acute stress responses, the scarcity of relevant data, and the need for both interventional designs and the consideration of mediators and moderators to understand underlying mechanisms.

Reference

Grimm, E., Agrigoroaei, S., Rohleder, N., & Becker, L. (2021). Executive functioning as a predictor of physiological and subjective acute stress responses in non-clinical adult populations: A systematic literature review and meta-analysis. *Neuroscience & Biobehavioral Reviews*, 131, 1096-1115. https://doi.org/10.1016/j.neubiorev.2021.09.037

2.1. Introduction

Adaptive from an evolutionary point of view, acute stress responses are common experiences for individuals in the 21st century. The exposure to events one perceives as threatening generates a series of sequential physiological and subjective reactions known as stress reactivity, which enable the individual to adapt to these situations accordingly (Epel et al., 2018). The first, immediate stress response is the activation of the sympathetic nervous system (SNS), the so-called "fight-or-flight" response, which releases the hormones epinephrine and norepinephrine and increases both heart rate and blood pressure (Selye, 1946). The second, delayed response is the activation of the hypothalamic-pituitary-adrenal (HPA) axis several minutes later, which leads to the secretion of the stress hormone cortisol from the adrenal cortex (Fulford & Harbuz, 2005; Selye, 1946). With a further delay, complex effects on the immune system are activated, such as an up-regulation of some components (i.e., inflammatory pathways) and down-regulation of others (i.e., cellular immunity; Chrousos, 2009; Morey et al., 2015). In terms of psychological responses, measurements often include perceptions of subjective stress, pressure, threat, and lack of personal control in light of one's personal resources. As an example, these responses may be activated during important examinations, such as taking university exams or receiving diagnostic results during medical appointments.

The stress response, however, is not limited to stress reactivity, and distinct phases can be distinguished along a time continuum. Anticipatory stress refers to the activation of the physiological and subjective responses after being informed about a future stressful situation, ahead of actual exposure to the stressor (e.g., the time period ahead of an important examination; Engert et al., 2013). Exposure is defined as the likelihood of being confronted with an event perceived as stressful, given one's personal vulnerability and resilience factors (e.g., having to partake in an important examination; Koffer et al., 2016). The recovery phase, following initial reactivity, is the time period during which activated stress systems return to baseline to allow for homeostasis (e.g., the time period following the end of the examination). Finally, habituation is characterized by an overall lower activation of the stress responses following repeated exposure to the same, or similar, acute stressors (e.g., having to partake in future examinations of the same kind; Grissom & Bhatnagar, 2009; Thompson & Spencer, 1966).

These acute stress responses are considered adaptive, as they generate both cognitive (e.g., appraisals of the situation) and behavioral (e.g., emotion regulation, coping strategies) responses that will enable individuals to face the stressor (Epel et al., 2018). When they become maladaptive, acute stress responses emerge as detrimental to one's health. Examples include the persistent anticipation of future events, underactive reactivity, prolonged recovery time when encountering a stressor, and the absence of habituation when exposed repeatedly to similar events (Epel et al., 2018). This maladaptive activation will lead to the cumulative wear-and-tear of the multiple physiological systems involved, a process otherwise known as allostatic load (Epel et al., 2018; McEwen, 1998). The long-term consequences are deleterious and include higher risk of cardiovascular disease (Guidi et al., 2021). Thus, identifying malleable protective factors that limit excessive stress responses to acute stressors represents an important research goal. While behavioral (e.g., physical activity), psychological (e.g., self-esteem), and social factors (e.g., social support) that could be targeted by interventions have been previously considered (e.g., O'Donnell et al., 2008), research regarding the protective role of higher-level cognitive processes, such as executive functioning, remains limited.

Executive functioning

Executive functioning is a higher-order neurocognitive control-system that enables individuals to organize their actions, to flexibly engage in goal- and future-directed behaviors, and to successfully adapt to changing environments (Jurado & Rosselli, 2007). As a multidimensional overarching construct, it comprises individual facets commonly referred to as inhibition, cognitive flexibility, updating, working memory, attentional control, and planning (Diamond, 2013; Friedman & Miyake, 2017; Snyder et al., 2015). Inhibition is the ability to prevent predominant, automatic, or inadequate responses. Cognitive flexibility, or set-shifting, is the capacity to switch between tasks, operations, actions, or cognitions. Verbal fluency is also considered to capture cognitive flexibility, reflecting the access to one's lexical repertoire and semantic memory, as well as the generation of new ideas and language content (Rende et al., 2002). Working memory updating is the constant monitoring of incoming information in working memory (a limited capacity cognitive system responsible for the temporary storage and processing of information; Baddeley, 2002), and the removal of content no longer relevant to the task. Attention can be divided into top-down and bottom-up processes. The former, otherwise known as attentional control, is one's ability to engage – and to maintain – one's attention upon information that is relevant to current tasks or goals (Engle, 2018). In the latter, a stimulus undergoes biased processing as a result of its particular salience (i.e., a specific characteristic such as stress-related information; Posner et al., 1984). Finally, mental planning enables individuals to generate roadmaps to reach specific goals, laying the foundations for goal-directed behavior.

Executive functioning and acute stress

The association between executive functioning and stress has been predominantly documented by studies examining cognitive impairments resulting from acute stress inductions or prolonged stressful experiences. For example, recent meta-analyses have investigated the effects of acute (e.g., Shields et al., 2016) and chronic stress (Allen et al., 2017) upon executive functioning. Despite existing theoretical accounts, the reverse association, where executive functioning represents a protective factor for adaptive stress responses, has not been the object of extensive, integrative research, systematic reviews, or meta-analytical efforts.

Differences in executive functioning emerging from genetic, neuroanatomical, physiological, cognitive, and environmental factors may represent a source of resilience for the different stress phases (Williams et al., 2009). In their review, Schmeichel and Tang (2015) outline the relevance of examining the distinctive role of executive functioning for emotion regulation. Inhibition may be particularly relevant for suppressing negative emotional responses to events, set shifting may be required for switching away from negative material, and updating may aid to modify emotional appraisals of negative events within working memory. More specific to optimizing stress regulation, Crum and colleagues (2020) describe several processes involved. These include (a) learning to select stressful situations that align with one's goals and to disengage when this fails to be the case, (b) deploying one's attention away from negative-related stimuli and towards goal-specific information, and (c) using reappraisal techniques. Fundamentally, the latter require the intervention and interaction of several executive functioning facets, including inhibition, task switching, updating, attentional control, and planning abilities.

Emerging behavioral and physiological research on the subject provides a promising opening on this research question. A study on frail individuals found that the likelihood of being exposed to potential stressful situations depended upon baseline executive functioning, with the most important factor being the individuals' ability to plan their daily activities (Roiland et al., 2015). Another study revealed that higher efficiency of attention alerting and orienting after exposure to negative, stressful cues led to increases in subsequent cytokine responses (Maydych et al., 2018). To summarize, limited work is currently available to allow for the identification of relevant, specific executive functioning facets and stress phases involved, as well as candidate moderators implicated.

Potential moderators

The last decade of research on executive functioning and stress has identified several potential moderators that may impact this cognition-stress association (Shields, 2020). First, participant characteristics may play a moderating role. Age-related changes for both executive functioning (e.g., deterioration across all facets with increasing age; Singh et al., 2012) and stress reactivity (e.g., increased systolic blood pressure reactivity with age; Uchino et al., 2005) are well established. Consequently, the consideration of chronological age is essential to understand how executive functioning variations influence physiological and psychological stress responses among younger, middle-aged, and older adults. Similarly, sex differences are also observed for executive functioning performance (Agrigoroaei & Grimm, 2021) and physiological responses to acute stress (Liu et al., 2017; Reschke-Hernández et al., 2017). Additionally, medication use may modulate physiological stress (e.g., antidepressants, antipsychotics, antihypertensive, oral contraceptives; Alvares et al., 2016; Granger et al., 2009), while smoking may also significantly impact HPA axis responses and cardiovascular reactivity (Sjoberg & Saint, 2011; Zänkert et al., 2019).

Second, aspects related to the task choice for executive functioning measurements also represent potential moderators. These include the presence or absence of emotional stimuli and the outcome type (i.e., performance-based vs. time-based indicators; Shields et al., 2016).

Third, the nature of the implemented acute stressor may be a moderator, as stressor type and severity may influence the degree of subjective and physiological stress responses generated (Shields et al., 2016). In addition, the time of day during which the study is carried out may moderate the relationship between executive functioning and the acute stress responses, as HPA and cardiac autonomic activity are subject to circadian variations (Shields, 2020; van Eekelen et al., 2004). Accounting for these factors in the current review and meta-analysis will enable a clearer understanding of the role of executive functioning for modulating stress responses.

Current study

In light of the potential benefits of higher executive functioning for acute stress responses, and the current lack of comprehensive approaches allowing for a precise, data-driven examination of these effects, we sought to (a) systematically review the association between baseline executive functioning and acute stress in healthy adults and to (b) quantify its strength using a meta-analysis. The goal of the current systematic review and meta-analysis was to establish whether distinct executive functioning facets (i.e., inhibition, cognitive flexibility, updating, working memory, attentional control, and planning) differ in their effect upon acute stress responses. We further sought to disentangle this cognition-stress relationship according to the specific stress indicators (i.e., both self-reported and physiological measures) and phases (i.e., anticipation, exposure, reactivity, recovery, and habituation) considered. We strived to incorporate results from correlational, longitudinal, and interventional studies, in which executive functioning was either tested or experimentally manipulated ahead of an acute stressor. The integration of these approaches should help to situate the operationalization of this research question in the literature. It will also bring to light existing experimental manipulations that seek to confirm the cause-and-effect relationship between executive functioning and stress regulation. We aimed to conduct separate meta-analyses for correlational, longitudinal, and interventional designs, when sufficient data was available, and to explore, statistically, the role of potential moderators of this association.

2.2. Methods

The current systematic review and meta-analysis was conducted in accordance with the PRISMA guidelines (Moher et al., 2009; see Supplementary Materials 1). The study protocol (ID: 42019122297) was published on PROSPERO on February 6th, 2019 and is accessible online (https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42019122297). All data sets and scripts are available as Supplementary Materials.

Eligibility criteria

We included studies using the following criteria: (1) design: randomized trials, longitudinal studies, or cross-sectional studies in which executive functioning (see the "information sources" subsection for a list of eligible facets) was assessed before the administration of a stressor or a measurement of acute stress. Cognitive tasks were allowed to be used as stressors, providing that they were different from the baseline measures of executive functioning; (2) sample population: healthy adult populations aged over 18; (3) intervention (if present): inclusion of at least one passive or active control group; (4) outcomes: both physiological and subjective (e.g., self-reported stress, tension, or nervousness levels on a scale from 0 to 10) measures of stress. These included responses of the (i) HPA axis (e.g., cortisol area under the curve with respect to ground, AUCg, and with respect to increase, AUCi), (ii) inflammatory system (e.g., C-reactive protein, interleukin-6), (iii) cardiovascular system (e.g., resting diastolic (DBP) and systolic (SBP) blood pressure, pulse pressure, heart rate), (iv) SNS (e.g., norepinephrine, epinephrine, alpha-amylase, skin conductance), and (v) parasympathetic nervous system (PNS e.g., heart rate variability, HRV). The exclusion criteria comprised (a) literature reviews, uncontrolled intervention studies, and case studies; (b) clinical populations (e.g., diagnosis of mood disorders, dementia, or chronic health problems); (c) younger populations (children or adolescents); (d) interventional studies focusing on training cognitive abilities other than executive functioning (e.g., memory or processing speed); (e) outcome measures relating to chronic and life stress, along with their long-term deleterious effects; (f) outcome measures of anxiety, which incorporate broader processes like worry (e.g., Shin & Liberzon, 2010); and (g) studies not written in English. There were no limitations regarding the year or type of publication.

Information sources and search

Between May 22nd and 30th, 2019, we conducted a systematic literature review of studies available on Cochrane, OpenGray, Proquest Dissertations and Thesis Global, PsycInfo, Pubmed, Scopus, and Web of Science. The search process involved combining terms pertaining to executive functioning, stress outcomes, and the presence of an intervention. Executive functioning was captured through the keywords "executive function*", "executive control", "cognitive function*", "cognitive control", "cognitive flexibility", "fluency", "attention* control", "selective attention", "inhibit* control", "inhibition", "planning", "shifting", "switching", "updating", and "working memory". The stress terms comprised "stress exposure", "stress anticipat*", "anticipatory stress", "stress react*", "stress recovery", "stress habituat*", "stress adaptat*", "repeated stress", "stress regulation", "acute stress", "physiological stress", "psychological stress", "self-reported stress", "subjective stress", "self-rated stress", "perceived stress", "cortisol", "c-reactive protein", "interleukin-6", "heart rate", "cardiovascular", "blood pressure", "norepinephrine", "epinephrine", "alpha-amylase", "skin conductance", "glucorticoid*", and "frequency spectral power". Finally, we entered the terms "intervention", "modification", "program", and "training" when seeking cognitive interventions. The full search terms and strings can be found in Supplementary Materials 1.

Study selection

Using EndNote, duplicates were removed and two reviewers (a PhD candidate and a post-doctoral researcher) independently screened titles and abstracts. Cohen's kappa was fair ($k = 0.24$; McHugh, 2012). Given the high number of abstracts to screen (see Figure 7 for the PRISMA flow chart), this led to the over prevalence of one category response, namely both raters deciding to exclude a study. As the kappa statistic is highly dependent upon response prevalence, its computation may lead to low levels of reliability despite a very high percentage agreement between raters (Cargo et al., 2015; Viera & Garrett, 2005). In light of this, we additionally report the latter, which was almost perfect (99.54 % agreement).

Once the full texts were retrieved, they were uploaded to the Covidence online platform (www.covidence.org), which was used for the remaining steps of the systematic review. Any disagreements between the two raters were resolved through discussion with a third reviewer (a university professor with a PhD degree). Reference lists from articles were retrieved and searched for additional studies. Furthermore, to reduce publication bias, we asked the authors of articles included in the full text extraction phase for any additional studies or unpublished data of which they might be aware. Three authors responded favourably, providing relevant papers that are included in the current systematic literature review. On April 4th, 2020, a search update was conducted using the same databases, search strings, screening, extraction, and reference list search procedures.

Data extraction

The two reviewers followed a standardized, pre-piloted extraction form to extract data pertaining to study identification (e.g., year, publication type, sponsorship source, country, setting), methods (e.g., design, executive functioning and stress measurements, stress phase, included covariates, stressor type), population (inclusion and exclusion criteria, sample sizes, baseline characteristics), interventional details (where relevant: setting, frequency, duration, attendance, dropout), and any reported relationship between executive functioning and acute stress outcomes. Inter-rater reliability was assessed using the intra-class correlation and Cohen's kappa for continuous and categorical variables, respectively. If multiple reports of a study existed, we selected the most recently published article. Cohen's kappa was good ($k = 0.76$), while both intra-class correlations ($ICC = 0.99$) and percentage agreement (88.43 %) were high.

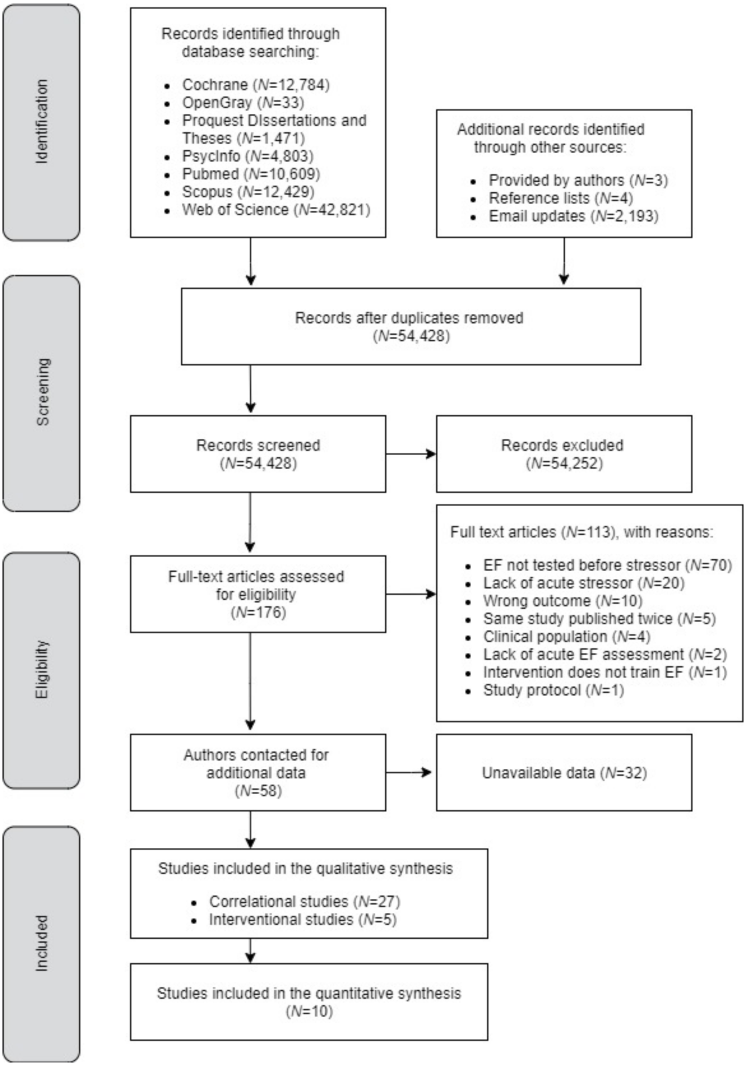

Figure 7. PRISMA Flow Diagram

All authors whose studies were included following the full text extraction stage were contacted twice to complete information such as the nature and the distribution of the sample, medication use, or smoking status of the participants. We also asked for specific correlations between baseline executive functioning facets and the change in at least one measure of physiological or subjective stress response, tailoring the requests to the study design and our definitions of stress anticipation, exposure, reactivity, recovery, or habituation (see Table 1).

Table 1. Definitions of stress phases investigated in the systematic literature review and meta-analysis

	Anticipation	Exposure	Reactivity	Recovery	Habituation
Cortisol and alpha-amylase	Change from the moment of stressor instructions to start of stressor		Change from pre-stressor values to peak values	Change from peak values to last measure obtained during the session	Comparison of reactivity and recovery levels when confronted to repeated or similar stressors
Heart rate and blood pressure	Change from the moment of stressor instructions to levels during instructions period		Change from pre-stressor values to average levels during stressor	Change from average levels during stressor to last measure obtained	
Self-reported measures	Change from the moment of stressor instructions to start of stressor	Confrontation with an event perceived as stressful or threatening	Change from immediate pre- to post-stressor levels	Change from immediate post-stressor levels to last measure obtained	

For studies in which participants were subjected to either a stressor or a control condition, we requested the correlations for the stress group, only. If we did not hear back from the authors, their data – where relevant – was retained for the qualitative synthesis whilst excluded from the meta-analysis. The asterisks in Table 2 mark the studies considered for the meta-analysis.

Risk of bias in individual studies

To assess risk of bias, we used two separate scales for cross-sectional and interventional studies. For the former, the same two independent raters used a modified version of the Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies (National Heart, Lung, and Blood Institute, NHLBI, 2021) and the "Biomarker Measurement" domain of the BIOCROSS Quality Appraisal Tool for Cross-sectional Studies using Biomarker Data (Wirsching et al., 2018; see Supplementary Materials 1 for further details regarding these modified scales). All correlational articles were attributed a score on these two subscales. Based on the proportion of criteria met out of those eligible, articles were rated as having (a) poor (less than 50% criteria met), (b) fair (between 50% and 75%), or (c) good (equal to or greater than 75%) quality.

For interventional studies, the Revised Cochrane Risk-of-bias Tool for Randomized Trials (RoB 2; Sterne et al., 2019) was used in combination with the BIOCROSS biomarker measurement domain. The RoB 2 evaluates five types of biases, arising from (a) the randomization process, (b) deviations from intended interventions, (c) missing outcome data, (d) outcome measurement, and (e) selection of the reported results. Each domain comprises sub-components in which raters must answer "yes", "probably yes", "no", "probably no", "no information", or "not applicable". These decisions follow an algorithm to generate a final rating at the domain level, specifying whether a study presents a low risk of bias, some concerns, or high risk. These grids were tested and discussed on a sub-sample of four studies, before full quality appraisal completion. Cohen's kappa indicated good agreement ($k = 0.74$) while the percent agreement reached 84.32%. The raw data for all three scales can be found in Supplementary Materials 2.

Meta-analysis procedure

Coding of variables

The differential temporality of physiological phases and indicators (e.g., Plieger & Reuter, 2020) complicated their merging into one coherent dataset. To decrease heterogeneity in cognitive tasks, stress phases, and stress outcomes, separate databases were created for each different stress phase. Based on the received data, we created three separate databases for anticipation, reactivity, and recovery. Given that physiological and subjective responses rarely correlate (e.g., Hellhammer & Schubert, 2012), and that executive functioning facets are conceptually different, we further divided the databases according to specific facets and stress outcomes (see script in Supplementary Materials 1). The first author repeated the coding procedure three times.

Based on existing literature, each cognitive task was labeled as measuring a specific executive functioning facet. The moderators were as follows: executive functioning measure (performance-based vs. time-based), presence or absence of emotional stimuli, stress indicator (e.g., cortisol, alpha-amylase), average age, percentage of female participants, presence or absence of medication use, smoking status (smokers excluded from study vs. not), time of day during which participants were tested (morning, afternoon, or all day), and publication year. In addition, we defined stressor type following Shields and colleagues' (2016) criteria. "Social" stressors included a social evaluation but lacked any component of pain (e.g., the Trier Social Stress Test, TSST; Kirschbaum et al., 1993). "Pain" stressors lacked a social evaluation but comprised an element of pain administration (e.g., the Cold Pressor Task, CPT). "Cognitive" stressors included a cognitive task as stressor, without the pain or social components (e.g., Paced Auditory Serial Addition Test, PASAT, Gronwall, 1977). Finally, "hybrid" tasks included any mixture of these three types of tasks (e.g., the Maastricht Acute Stress Test, MAST, Smeets et al., 2012). Moreover, we considered the severity of the stressor as a potential moderator. We applied Shields and colleagues' (2016) categories based on stressor elements known to trigger cortisol response (Dickerson & Kemeny, 2004). The severity of the stressor was coded as low (0) if it did not include a social, nor a pain component (e.g., PASAT). Moderate-low stressors (1) comprised either one element of social evaluation or pain (e.g., CPT). Moderate stressors (2) applied pain and included one social-evaluative element (e.g., Socially-Evaluated Cold Pressor Task, SECPT; Schwabe & Schächinger, 2018). Moderate-high stressors (3) included two elements of socio-evaluative measures (e.g., the TSST).

Computing effect sizes

As the heterogeneity among study designs did not allow for the direct computation of effect sizes of comparable data, we only included Pearson's product-moment correlation coefficient *r* that we received from authors by email. Where relevant, correlations were inversed to represent a correlation between *better* executive functioning and change in a stress measure before (anticipation), during (reactivity), or following the stressor (recovery). Moreover, while increase in cortisol, heart rate, or blood pressure are synonyms of increased stress during reactivity, the opposite is true for specific HRV measures such as High Frequency power HRV (HF-HRV) and Root Mean Square of the Successive Differences (RMSSD; Kim et al., 2018). Any correlation pertaining to the latter were further inversed to enable appropriate comparison of effect sizes. All recovery correlations were further inversed to represent *faster* recovery (i.e., faster decreases in cortisol and faster increases in HF-HRV during the recovery period). We did not conduct a meta-analysis on interventional studies, as they varied considerably in terms of training administered and stress outcomes evaluated (see Table 3).

Data analyses

Main analyses

We completed data analysis on RStudio Version 1.4.1103. The script and all databases are available as Supplementary Materials. Pearson's product-moment correlation coefficient r were transformed using Fisher's Z, as recommended (Borenstein et al., 2011). Common meta-analytical approaches assume that the effect sizes are independent. However, given that both executive functioning facets and stress outcomes involve various assessment types, most authors provided multiple effect sizes per study. To handle the dependency between these – and to avoid losing information or increasing the likelihood of Type I errors by aggregating them (Hedges, 2007) – it is recommended to apply a robust variation estimation method (RVE; Fisher & Tipton, 2015; Hedges et al., 2010) or a three-level meta-analysis (Cheung, 2014, 2019; Konstantopoulos, 2011). For meta-analyses of a limited number of studies (< 25), multi-level models tend to underestimate variances, thereby leaving RVE as the preferred choice (for recommendations, see (Moeyaert et al., 2017; Scammacca et al., 2014).

To implement RVE, we used the *robu*() function of the *robumeta* package (Fisher & Tipton, 2015). RVE estimates an overall effect size as a weighted mean of the observed effect sizes across studies, even when information regarding effect size covariance is missing. We applied small-sample adjustments for estimates and degrees of freedom (*df*), as recommended when the study sample amounts to less than 40 studies (Tipton, 2015). The ρ was set to the recommended level of 0.80 (Tanner-Smith et al., 2016). The *dfs* for all analyses were estimated using a Satterthwaite approximation, where $df = 2/cv^2$ and *cv* represents the coefficient of variation. Given that this approximation holds only if the degrees of freedom are above four (Tanner-Smith et al., 2016), we only reported significant effect sizes when this condition was met, and when $p < .05$. We performed Grubbs' test to detect the presence of outliers and planned to run sensitivity analyses with and without outliers should the test be significant.

Heterogeneity

Heterogeneity was evaluated using both τ^2, which represents the between-study variance (Hedges et al., 2010), and with I^2, which quantifies variance in effect sizes as a result of effect size heterogeneity rather than sampling error (Borenstein et al., 2017). There is no heterogeneity when τ^2 equals zero (Quintana, 2015). In addition, low, moderate, and high variance can be identified when I^2 is 25, 50, and 75, respectively (Higgins et al., 2003).

Moderator analyses

We planned to perform meta-regression models on the main relationship between executive functioning and stress using RVE. We evaluated the effect of each moderator separately. Continuous predictors were directly entered into the model, as were two-level dummy-coded categorical predictors. We planned to use the *clubSandwich* package to run the Wald statistic to assess the significance of multi-level categorical predictors.

Publication bias

The *robumeta* package does not currently enable the evaluation of funnel plots and funnel plot asymmetry when several effect sizes are nested within studies. Thus, we conducted small-sample bias analyses on the aggregated effect sizes per study using the *metacor* function of the *meta* package (Balduzzi et al., 2019). We visualized contour-enhanced funnel plots (Peters et al., 2008) and conducted both Egger's test of the intercept (Egger et al., 1997) using *dmetar* (Harrer et al., 2019) and Duval & Tweedie's trim-and-fill procedure (Duval & Tweedie, 2000). We searched for outliers and influential cases using the aggregated databases.

2.3. Results

Study selection and characteristics

The current qualitative review revealed 26 correlational and five interventional articles with exploitable data on the role of executive functioning in relation to anticipation, exposure, reactivity, recovery, and habituation following the administration of an acute stressor. As illustrated in the PRISMA flowchart (Figure 7), the search revealed a total of 84,950 articles, with three additional articles received from authors, four from reference lists, and 2,193 through the updated search in April 2020. After identifying duplicates and screening abstracts for relevant inclusion criteria, a total of 54,252 articles were excluded. Given the broad search criteria at this stage, numerous hits were particularly irrelevant, stemming from fundamental research in biomedical domains. Examples for these include the investigation of chronic health conditions, animal or clinical populations, implementation of drug clinical randomized-controlled trials, and failing to include both executive functioning and acute stress within the same design.

Data was extracted from 176 articles, and 113 were excluded with reasons (see Figure 7). Fifty-eight articles contained the appropriate methodological design to calculate Pearson product-moment correlations between executive functioning and subsequent acute stress, but only 18 articles reported a relevant association. The thirteen authors that responded to our email requests were considered for the meta-analysis (including five of whom had reported an exploitable association in their original article). One article (R. K. McHugh et al., 2010) reported two independent studies, leading to 27 correlational studies for the qualitative synthesis. Overall, high heterogeneity in the task choice for attentional control was observed in the three studies investigating this facet. While these results are discussed in the qualitative synthesis, the high diversity prevented us from merging them quantitatively into a coherent meta-analysis. Consequently, 10 studies remained for the latter. The qualitative review separately discusses results from correlational and interventional designs.

Review of correlational studies

Study characteristics

The complete set of data included 1,980 participants (range: 20 – 360 per study). Full characteristics for each individual correlational study are presented in Table 2. It is important to note that 15 of the retained studies (57.69%) explicitly aimed at investigating the predictive or moderating role of executive functioning on stress exposure, reactivity, and/or recovery. None initially intended to study executive function in relation to stress anticipation.

With respect to study design, the majority of the articles investigated only one executive functioning facet (76.92%). The most represented components were attentional control ($N = 9$), inhibition ($N = 9$), and working memory ($N = 8$). Flexibility and updating were assessed in five and three studies, respectively. There were no studies on planning. In terms of implemented acute stressors, all but two studies measured stress in the laboratory, with social stressors (64.00%) and moderate-high intensities (52.00%) being most common. Seven studies included a control group. Outside the laboratory, one study used an unmanned aerial vehicle simulation field stressor, and another studied daily stressors using ecological momentary assessment procedure. With regard to stress phases, two studies (7.41%) investigated exposure to stressful events, three (11.11%) included anticipation, all 27 (100.00%) assessed reactivity, and 12 (44.44%) studied recovery. Indicators relating to cortisol were most frequently used at all phases except for anticipation, for which heart rate and HRV were more frequent.

Quality appraisal

All articles clearly reported the research question. They also defined and implemented valid and reliable measures of executive functioning and acute stress. Four articles did not report manipulation checks that would ensure the validity of their stressor. Most articles adequately defined the population inclusion and exclusion criteria (92.31%), although the majority did not report on the period during which the population was recruited (88.46%), did not provide the required information to calculate the eligible rate (88.46%), and failed to present a sample size justification (80.77%). In the original analyses, the majority of articles (72.22%) included sex as a covariate, but other important covariates, such as medication intake (oral contraceptives included), smoking, specific menstrual cycle phases, and age (e.g., Laborde et al., 2017; Shields, 2020; Zänkert et al., 2019), were not systematically considered by authors.

With respect to biomarker information, almost all articles (91.67%) adequately described assay methods, preservation, and storage. Only 58.33% reported the laboratory in which the biomarker analyses were conducted, 52.63% detailed the quantitation methods, and 26.32% explained the reproducibility assessments. Where relevant, all articles failed to report whether the analyses were blinded for laboratory staff. Biomarker distribution, outliers, and measurement inaccuracies were reported by 58.33%, 50.00%, and 28.00% of articles, respectively. Overall, 23 articles were rated as “fair” and three as “good” on the NHLBI subscale. On the BIOCROSS subscale, 13 articles were rated as “poor”, five as “fair”, and eight as “good”.

Results of individual correlational studies by stress phase and executive functioning facet

Exposure

Participants with higher or lower inhibition abilities did not differ in terms of number of recent life events (Xin et al., 2019), while attentional bias towards negative material did not predict the frequency of daily negative events (Iijima et al., 2018).

Anticipation

A negative and significant association was observed for attentional control (Schwerdtfeger & Derakshan, 2010), whereby longer times to disengage from angry faces predicted lower – and less healthy (see Kim et al., 2018; Shaffer & Ginsberg, 2017) – change in HF-HRV and RMSSD during stressor anticipation. Similarly, another study (Roos et al., 2017) reported a significant positive association between better baseline inhibition abilities and greater, more adaptive HRV increase in anticipation of the stressor. These results were not replicated for heart rate. Regarding cortisol, there were no significant associations with flexibility and working memory (Fiocco et al., 2007).

Reactivity

Inhibition. Better inhibitory abilities were associated with stronger cortisol reactivity in both correlations (Xin et al., 2019) and hierarchical regression models (Morrison, 2014). In the latter, the interaction between inhibition and disengagement bias from threat was also significant, where greater difficulties disengaging from threat-related material, compared to neutral, predicted stronger cortisol release in individuals with longer inhibition reaction times. For individuals with higher inhibition abilities, longer disengagement times from neutral materials was associated with stronger cortisol reactivity.

In terms of HRV, two studies reported significant associations between inhibition and more adaptive HRV reactivity. In one study (Xin et al., 2019), lower – but not higher – inhibition abilities moderated the relationship between exposure to recent stressful events and smaller change in RMSSD and HF-HRV during the TSST. The absence of findings for higher executive functioning was interpreted as resulting from these individuals' more effective coping abilities (i.e., flexible and adaptive appraisal of stressful life events) given a better performance of the prefrontal cortex. Similarly, better inhibition abilities predicted greater LF-HRV reactivity in a regression model (Mehta, 2012), but the result was no longer significant after applying Bonferroni corrections.

Finally, one study found that better inhibition scores predicted less subjective distress to a field stressor (Panganiban, 2013). Though a mediational model was not tested, better inhibition was also a negative predictor of task-related threat appraisal and feelings of uncontrollability, which could represent underlying mechanisms. Overall, the absence of an association between inhibitory abilities and stress reactivity were otherwise reported in six studies, with respect to cortisol, alpha-amylase, blood pressure, heart rate, HRV, skin conductance levels, and subjective stress.

Cognitive flexibility. Associations for flexibility are scarce, emerging for skin conductance and cortisol only. In multiple linear regression models (Hendrawan et al., 2012), better verbal fluency was associated with less cortisol and skin conductance reactivity. Better task-switching scores also significantly, and negatively, predicted skin conductance levels. The authors postulated that executive functioning, dependent upon the frontal lobes, may allow individuals to efficiently integrate goal-related cues, organize and implement coping action plans, and continuously monitor and adjust behavior accordingly. The fact that the verbal fluency task may mobilize multiple cognitive facets in itself may explain its greater association with stress reactivity. In another study, better task-switching was associated with overall less cortisol output during the TSST (AUC_g), but not with increase (AUC_i; Guevara & Murdock, 2019). Task-switching did not predict AUC_i, and simple bivariate correlations with cortisol change were not significant. Hence, while flexibility may not be associated with initial cortisol increase, it may be linked to less prolonged cortisol release over the session. Two studies replicated the absence of the association with both percentage increase and change in cortisol (Fiocco et al., 2007), as well as blood pressure and HRV (Mehta, 2012). Flexibility was not associated with distress (Panganiban, 2013).

Working memory updating. Three studies reported correlations with cortisol, subjective distress, and stress cytokines, respectively. Lin and colleagues (2020) identified longer 2-back reaction times as being significantly correlated with – and a predictor of – less cortisol reactivity. This was not replicated for 2-back accuracy or the 3-back task. The authors suggested that speed, but not performance, may be key in this association. Faster responders may be better able to mobilize their cognitive resources on a daily basis, leading to, overall, more reactive HPA responses. They further hypothesize that excessive task load in the 3-back level may have a role to play in the absence of an association. Panganiban (2013) found that updating significantly predicted greater subjective distress under low task load (i.e., less demanding stressor) in a hierarchical multiple regression model. The researcher explains that individuals with greater updating abilities may be allocating their extra resources to stress processing, and that individuals should be trained to refocus these abilities upon task-relevant information instead. Finally, there were no significant associations (bivariate correlations and regression analyses) between updating and salivary interleukin-1β, interleukin-6, and tumor necrosis factor-α reactivity (Quinn et al., 2019).

Working memory. The results for working memory provide the clearest picture. Seven independent studies report no significant correlation between measures of working memory and cortisol, alpha-amylase, and subjective stress reactivity. LeMoult and colleagues (LeMoult et al., 2019) compared whether the association between working memory and cortisol reactivity and recovery differed between health individuals and patients with generalized anxiety disorder (GAD). Lower working memory was associated with a greater increase in cortisol reactivity in GAD patients only. The authors hypothesized that healthy individuals may be implementing efficient coping strategies and/or attenuating emotions faster than clinical populations, which would explain the findings. In contrast, one study (Almela et al., 2014) reported a curvilinear relationship between spatial working memory scores and cortisol AUC_i. They also find this effect for forward spatial length in women, and backward spatial length in men. They explain their findings for individuals with lower working memory on account of the effects of repeated stress upon cognitive functioning. When exposed to a threatening situation, an increase in cortisol is adaptive (i.e., Dickerson & Kemeny, 2004). The absence of a cortisol response in these individuals is indicative of the HPA-axis performing under optimal threshold. Repeated over time, this may lead to deteriorations of these individuals' executive functioning abilities. The lower response in individuals with better cognitive abilities was attributed to the fact that they may be generally less stressed by the cognitive nature of the TSST, given their higher abilities.

Attention. Overall, all but two studies reported significant associations with respect to both early attentional biases and later voluntary control of attention. In terms of attentional biases, higher unaware bias towards negative material predicted stronger cortisol reactivity to both a laboratory stressor and field-based examination stress (Fox et al., 2010). Moreover, the same bias was positively correlated with overall cortisol release throughout these sessions. The other three attentional biases investigated were unrelated to any of these stress measures. Similarly, a moderating role of attentional biases and subjective stress was detected in Iijima and colleagues' (2018) study. Compared to individuals with low attentional bias towards negative material, those with higher scores presented stronger increases in tension-anxious mood during a stressful event. The results from these two studies suggest that preconscious bias towards negative cues may exacerbate subsequent subjective and physiological stress reactivity.

In another study, however, high cortisol responders – compared to low cortisol responders – presented stronger baseline *avoidant* attentional bias to threat (i.e., shorter RTs for angry vs. neutral faces; Roelofs et al., 2007). The authors highlight the importance of incorporating social threat-related material, as these findings were not replicated for happy or neutral material. Interestingly, cortisol responders presented high threat attentional bias *following* the TSST. The authors presume that the initial avoidant response may serve an adaptive function under rest conditions, as it limits excessive physiological arousal, but may fail under stress and lead to higher reactivity thereafter.

With respect to the voluntary control of attention, engagement and disengagement also seem to influence stress reactivity. Higher engagement towards stress-neutral words was significantly, negatively associated with cortisol AUC_i (Pilgrim et al., 2010), over and above the role of sex. Slower engagement was indicative of less cortisol increase, and further analyses revealed that individuals who, based on a median split, were slower to engage with stress-related stimuli presented a 3% *decrease* in response to the TSST, while fast engagers observed an *increase* of 81%. Given that the university sample in this study presumably had previous experience with speech-related activities, the authors interpreted the decrease in cortisol as habituation (i.e., an adaptive response). Rapid engagement of one's attention towards negative information, however, appears to magnify cortisol responsivity. Interestingly, the latter individuals also presented lower self-esteem, which could act as a moderator of this association.

Similarly, in one study (Sanchez et al., 2017), longer times to disengage from happy faces, and to engage with both disgust and sad stimuli were negatively associated with self-reported subjective tension in response to a stressor. In Schwerdtfeger and Derakshan's (2010) study, rapid disengagement from angry faces was similarly associated with – but also predicted, in a hierarchical model – stronger decrease in HF-HRV during a speech task. In contrast, engagement towards angry or happy faces was unrelated to HRV. Although not tested, the authors suggested that this might be the result of individuals re-engaging their attention towards goal-specific information and invoking active coping strategies.

Recovery

Across the 10 studies with measures of post-stressor recovery, four reported significant associations with executive functioning. One study (Xin et al., 2019) revealed a negative correlation with inhibition, so that higher performance was associated with slower cortisol recovery (but not heart rate or HRV). In contrast, Mehta (2012) found that inhibition was a positive predictor of post-TSST immediate LF-HRV and HF-HRV recovery, along with delayed HF-HRV. Findings from Fiocco and colleagues (2007) provided a statistical trend, where the association between verbal fluency and quicker cortisol recovery from the stressor approached significance. Another study (Sanchez et al., 2017) found that longer times to engage with disgust stimuli was associated with faster recovery from subjective tension. None of the other engagement and disengagement indices were correlated with neither subjective stress nor HRV.

Synthesis of meta-analysis

The databases contained six effect sizes (range: two to four per study; $N = 152$) from two studies for anticipation, 28 effect sizes (range: one to six per study; $N = 499$) from 10 studies for reactivity, and 24 effect sizes (range: two to six per study, $N = 410$) from seven studies for recovery. Given that the anticipatory dataset comprised two studies and six outcomes, the RVE analyses suffered a lack of statistical power. As a result, anticipation was not further analyzed.

Similarly, due to low available degrees of freedom for the analyses, we were unable to calculate associations between cognitive flexibility and (a) cortisol (*number of studies*, $n = 2$, *effect sizes*, $k = 3$), SNS ($n = 0$), and subjective reactivity ($n = 0$), or with (b) cortisol ($n = 2$, $k = 3$), SNS ($n = 0$), and subjective recovery ($n = 0$). For the same reasons, RVE analyses could not be run for the associations between inhibition and cortisol ($n = 3$, $k = 4$), SNS ($n = 3$, $k = 7$), and subjective reactivity ($n = 1$, $k = 2$), or with cortisol ($n = 3$, $k = 4$), SNS ($n = 2$, $k = 5$), and subjective recovery ($n = 1$, $k = 2$).

Working memory

There was as small, significant negative association between working memory and cortisol reactivity ($r = -.09$ $p = .025$, 95% CI [-0.15, -0.02]), indicating that better executive functioning was associated with less cortisol reactivity to the stressor. Heterogeneity was low, as I^2 and τ^2 both equaled 0.0. Sensitivity analyses indorsed the robustness of the results, as the model estimates remained unchanged with increasing or decreasing ρ values. The forest plot is presented in Figure 8. Applying Grubbs test failed to detect significant outliers, as did the outlier detection and influential case analyses on the aggregated dataset. Unfortunately, there were insufficient degrees of freedoms available for any of the planned moderator analyses. Additionally, there was a lack of available results for associations with cortisol recovery (*n* = 5, *k* = 8), as well as SNS and subjective stress reactivity (*k* = 1) and recovery (*k* = 1). This hindered the possibility of interpreting RVE analyses for these associations.

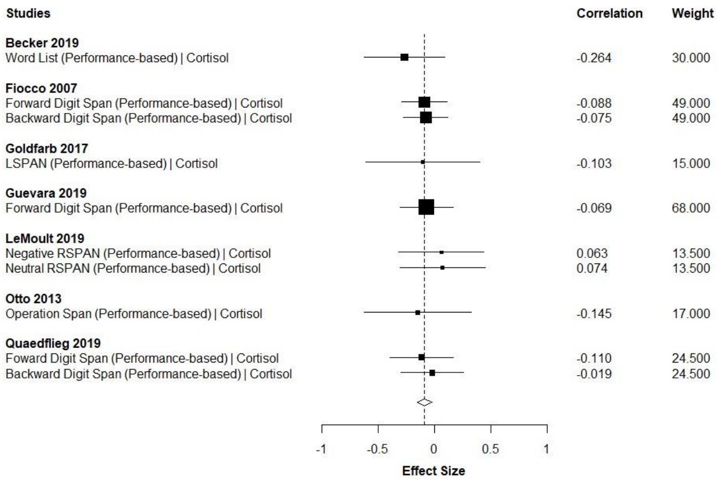

Figure 8. Forest plot of the correlations between working memory and cortisol reactivity

Publication bias

As the authors of grey literature (i.e., Master and PhD theses) did not provide correlations following our email requests, they were not incorporated into the meta-analysis. Funnel plot analysis for the working memory and cortisol reactivity database showed that all studies were dispersed symmetrically around the pooled effect size within the funnel itself. None of the effect sizes were found in regions of statistical significance (in grey) in the contour-enhanced funnel plots for working memory (Figure 9). Egger's test (Egger et al., 1997), which tests the null hypothesis that the funnel plot is asymmetric, further confirmed the absence of bias (z = -0.16, p = .832). The trim-and-fill analyses revealed that no modifications (i.e., additions or subtractions of studies) needed to be made. Hence, given these statistical findings, and that authors provided specific correlations tailored to our research questions, it is unlikely that the findings emerge from a potential publication bias.

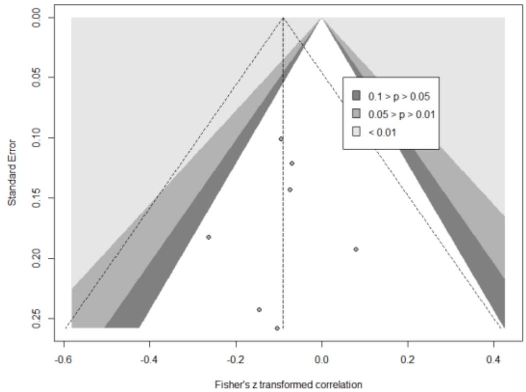

Figure 9. Contour-enhanced funnel plot investigating publication bias on the aggregated reactivity data

Review of interventional studies

Study characteristics

The search revealed five interventional studies, with four targeting attentional control (Dot-Probe Task and/or Spatial Cueing Attentional Bias Modification, ABM), and one focused upon working memory updating (affective and non-affective N-Back Task). The complete set of data included 276 participants (range: 28 – 69 per study). All interventions included emotional material and comprised at least one active control group. All training programs were individualized and computerized. Two interventions required participants to complete the tasks from home, either online or on a provided laptop, while the remainder required access to the university laboratory. Interventions lasted during one to six sessions (*M = 3.20*) of 19 to 45 minutes. Those comprising several sessions all occurred on consecutive days. The full characteristics are presented in Table 3.

With respect to stressors, the majority of the studies resorted to a hybrid stressor of moderate-high severity (60.00%). While none of the studies considered exposure or anticipation, all studies investigated stress reactivity. Most of the studies in the latter (60.00%) included repeated measurements of salivary cortisol. In contrast, only cardiovascular measures (heart rate, HRV, and blood pressure) were considered in the two studies that investigated recovery. Pilgrim and colleagues (2017) administered the TSST twice at a two-month interval, thereby qualifying as the only study assessing habituation.

Risk of bias

Overall, the raters identified three studies as having some concerns of bias and two as presenting high risk. One study (Pilgrim et al., 2014) was rated as high risk of bias regarding the randomization process, with training groups presenting significant differences in depression symptoms at baseline. There were some concerns regarding deviations from the intended interventions across all studies, but outcome data was available for all participants, and the risk of bias for outcome measurement was low. Although we lacked the evidence to claim the studies did not report expected analyses of their data, a plan of intended analyses was missing for each. One study was rated as having high risk of bias in the selection of reported results (Higgins & Hughes, 2012).

With respect to the BIOCROSS subscale, two studies were rated as "poor" and the three others as "fair" (see Table 3). All studies appropriately reported specimen characteristic, as well as the location of the laboratory for biomarker measurement. When relevant, quantitation methods and quality control procedures were correctly described by 66.67% of authors. The distribution of biomarker data was reported by 60.00% of the studies, while only 40.00% of authors reported on outlier detection and handling, and 33.33% on reproducibility assessments for biomarker stability. There was no information regarding the blinding of laboratory staff, nor did any article discuss possible errors resulting from measurement inaccuracies.

Results of individual interventional studies by stress phase and executive functioning facet

Reactivity

Pilgrim and colleagues (2014) found that participants in the masked and supraliminal groups showed higher cortisol increase (AUC_i) – but not overall cortisol output (AUC_g) – compared to controls. Contrary to expectations, individuals in the supraliminal training (with full conscious awareness of the stimulus) also presented overall higher sAA AUC_i and AUC_g compared to both masked (limited conscious awareness of the stimulus) and controls. Similarly, individuals in the spatial cueing training and gender identification control group in Pilgrim and colleagues' (2017) study also presented higher cortisol AUC_i to the first TSST, compared to the passive control condition and when controlling for sex. This was not the case for the Dot-Probe ABM. Synonyms of poor stress regulation, these findings are contradictory. The authors identified several limitations to the spatial cueing paradigm implemented that could explain this. In addition, they suggested that while attentional training may be successful in reducing stress reactivity in individuals suffering from clinical disorders, this may not be the case of healthy populations.

Furthermore, a hierarchical multiple regression model in Pilgrim and colleagues' (2014) research revealed that baseline attentional control moderated the relationship between Spatial Cueing training and reactivity, whereby the intervention increased cortisol levels in individuals with higher baseline attentional control only. The authors reference the dual system perspective on information processing (e.g., Ouimet et al., 2009). Threat processing involves two steps, the first of which includes a rapid, automatic associative network, followed by a slower, reflective system. Given that individuals with high attentional control are thought to prioritize rule-based processes to govern stress responses, it is plausible that the intervention trained the associative system, leaving the rule-based system – and the subsequent stress response for these individuals – intact. This moderator effect was not replicated in their more recent study (Pilgrim et al., 2017), demonstrating the need for further research to test this theory.

Baert and colleagues' (2012) findings report no main effect of attentional training upon self-reported tension or HRV. While Higgins and Hughes (2012) replicated these findings for DBP, SBP, and heart rate, they did find a significant interaction between time, intervention group, and neuroticism for SBP. In the anti-negative group, participants high on neuroticism showed normal SBP responses, while those low on neuroticism showed excessive reactivity to the stressor. The opposite pattern was true for the control training, during which a bias *towards* negative material was induced. Individuals low on neuroticism may have less exposure to events perceived as stressful and, consequently, less practice in optimal strategy choosing. Avoiding stress-related cues during the anti-negative training may have led to subsequent poor coping implementation and, ultimately, to an exaggerated stress response to the impending stressor.

Beyond these results for attentional training, there was no main effect of updating training on cortisol reactivity in Quinn and colleagues' (2014) study. They do report, however, a significant interaction between intervention group and ruminative tendencies. Relative to participants in the control group, individuals with *higher* – but not lower – ruminative tendencies in the training group benefited from lower cortisol reactivity.

Recovery

In one (Baert et al., 2012) of the two studies on recovery, executive functioning training provided more promising results. A significant increase in RMSSD during recovery was observed for the training group only, indicating faster return to baseline. In the control group, relative to the training group, the LF/HF ratio and LF units increased post-stressor, while the HF units decreased. While the stress response returned to baseline in the intervention group, it pursued its increase in controls.

Habituation

Pilgrim and colleagues (2017) found that participants in both trainings presented lower cortisol reactivity to the second TSST compared to those in the passive control group, even when controlling for sex. A hierarchical multiple regression model predicting cortisol change from TSST 1 to 2 indicated a statistical trend towards an interaction between baseline voluntary attention and training group. Simple slope analyses showed that participants with *low* – but not high – baseline voluntary attention, in both training groups, presented significantly less cortisol reactivity compared to the two control groups. These emerging findings highlight the potential for long-term effects of the ABM paradigms and point to the requirement of accounting for baseline attentional capacity when planning interventions.

2.4. Discussion

This systematic literature review and meta-analysis is the first to evaluate the extent to which executive functioning represents a protective factor for acute stress responses with respect to anticipation, exposure, reactivity, recovery, and habituation in healthy adults. Integrating findings from correlational and interventional designs, we aimed to identify the precise executive functioning facets involved in this association. Moreover, we strived to differentiate the stress phases and indicators influenced by executive functioning, and to explore the role of potential moderators of this cognition-stress association.

Answers from correlational studies

Systematic literature review

The current review confirmed significant associations between executive functioning and acute stress responses, though this was highly dependent on the facet and stress phase considered. To begin with, no significant associations were reported for stress exposure. With respect to anticipation, however, inhibition and attentional control were related to more adaptive HRV responses. As the effect did not extend to cortisol, the regulative role of executive functioning may be limited to associations with anticipatory responses of the sympathetic and parasympathetic nervous systems.

In comparison, reactivity was the most frequent phase taken into consideration by researchers, and attentional control emerged as the facet that was most often associated with it. More specifically, pre-conscious attentional biases towards threat-related cues were found to enhance the initial cortisol response, while the more voluntary control of attention away from negative information, and towards positive material, appeared to lead to more adaptive stress responses. These findings are in line with attentional processing theories (e.g., Bardeen & Read, 2010). In the context of the appearance of posttraumatic stress symptoms following exposure to a traumatic event, these theories postulate that higher-order attentional control may aid in the avoidance of threat-related material to reduce emotional arousal to the event. The current review suggests that these adaptive attentional processes may already be involved when exposed to stressful – though not traumatic – events. The results also support Crum and colleagues' (2020) model of stress optimization, where cognitive control is hypothesized to be fundamental to steer one's attention away from negative stimuli towards goal- or task-specific information, in order to limit excessive stress responses. While attentional control may be a transdiagnostic, protective factor for psychopathology (Bardeen et al., 2015), the current results extend this protective role to non-clinical populations and acute, non-traumatic stressors.

Associations for other facets were particularly limited, with a few correlations emerging for inhibition (more moderate HRV responses, less distress, higher cortisol), flexibility (less skin conductance and overall cortisol output), working memory updating (weaker cortisol reactivity, higher subjective stress), and working memory (curvilinear association with cortisol reactivity). Given these observations, attentional control appears most specifically relevant for stress regulation, while the other emerging associations require further replication given the diversity of stress indicators considered.

Finally, of the significant correlations, better inhibition and longer attentional engagement with disgust-related stimuli were associated with faster HRV and subjective recovery to an acute stressor, though inhibition was also associated with slower recovery. Although these emerging results indicate the presence of an association between executive functioning and recovery, it seems complicated, at this stage, to conclude the specific facet and stress outcome to which it pertains.

Meta-analysis

Attributable to limited available data for other associations, the meta-analysis focused on working memory and cortisol. Interestingly, while each independent study did not report significant correlations in their original article, their combination within a meta-analysis revealed a small, but significant, negative association. Better working memory at baseline was associated with lower subsequent cortisol change to the acute stressor.

Research on stress and health has brought to light that stress reactivity is a normative process spread across a continuum. Both blunted and excessively high reactivity are associated with unhealthy behaviors, negative health outcomes, and disease (e.g., Lovallo, 2011; Phillips et al., 2013). For example, the cumulative effect of sustained repetitive activation and adaptation of physiological systems in response to stressors ultimately leads to their wear-and-tear and, subsequently, to long-term health problems (i.e., allostatic load, McEwen, 1998). A moderate reaction to stress is therefore considered the most adaptive (Lovallo, 2013). The current meta-analysis indicates that higher executive functioning may limit excessive cortisol release, potentially preventing physiological dysregulation.

Answers from interventional studies

In line with correlational studies, a distinct finding of this review is the lack of interventions targeting multiple facets of executive functioning, in addition to the fact that the facets targeted by trainings were limited to attentional control and updating. Overall, the proposed attentional trainings did not appear to have a positive impact upon stress reactivity, but they did promote faster – and thereby, more adaptive – HRV recovery. However, interesting findings were noted for updating and reactivity, where working memory updating training led to significant reductions in cortisol reactivity if participants presented high – but not low – ruminative tendencies. Converging with findings from correlational studies, *training* individuals to modify their attentional focus away from threatening material, and towards positive information, may therefore play an important role for homeostasis.

Moreover, attentional processes may also be implicated in regulating physiological return to baseline and limiting sustained, maladaptive activation of stress systems. In fact, ABM displayed promising long-term effects for habituation to repeated stressors. It is important to note, however, that the evidence for its efficacy and reliability as first choice of treatment for anxiety disorders is limited (McNally, 2019). While stress and anxiety are inherently different processes, this existing limit in the field of clinical psychology should be acknowledged when applying such paradigms to stress research.

Age-related, cognitive, and behavioral mediators and moderators of the association

Although the lack of statistical power in the meta-analysis precluded us from running moderator analyses, the qualitative synthesis did reveal the existence of other mediators and moderators. Personality, threat appraisal, coping, and rumination emerged as candidates. First, individuals with lower scores of neuroticism trained to displace their attention away from negative material presented an *exaggerated* stress response to the stressor and sustained activation after stressor termination. While research is clear on the different implications of personality factors for acute stress responses (Xin et al., 2017), less is known about their relationship with executive functioning. Higher difficulties in subjective executive functioning have previously been associated with higher scores of neuroticism and lower conscientiousness (Bell et al., 2020), while other authors propose that executive functioning may play an important role in the expression of neuroticism and conscientiousness (Forbes et al., 2014). More recently, Montoliu and colleagues (2021) reported that higher neuroticism was related to poorer cognition four years later. Interestingly, this relationship was mediated by higher perceived stress. The dynamics of this cognition-stress relationship therefore require further work spanning other dimensions of personality.

Second, one study found better inhibition and worse updating to be associated with lower threat appraisal and stress uncontrollability. According to the Transactional Stress Model (Lazarus & Folkman, 1984b), the experience of physiological and self-reported stress results from two consecutive types of cognitive appraisal, namely primary and secondary appraisal. The former refers to the perception of the situation as a threat, challenge, or both, while the latter assesses the extent to which one can act upon the situation, accounting for situational demands, one's personal resources, and realistic potentials of control over the stressor (Gaab et al., 2005; Lazarus & Folkman, 1984b). Research on the role of executive functioning and stress appraisal is scarce, though a negative association has previously been reported between working memory and threat appraisal (Zandara et al., 2016). In accordance with accounts of cognitive control of emotion, executive functioning is thought to play a role in the reappraisal of stressful situations (Crum et al., 2020; Ochsner et al., 2012). Ultimately, stress appraisal can highly modulate one's subsequent subjective and physiological stress responses, and may lead to applying various coping strategies, thereby playing a key role in regulating an individual's reaction to daily stressors and life events.

In line with the finding above, several authors also advocate coping implementation as a mechanism of action. Coping depends on several executive functioning facets, which could explain the presence of a coping deficit (i.e., coping choice leading to sustained reactivity to the stressor) in individuals with poorer executive functioning. Recent research (e.g., Nieto et al., 2020) revealed that older adults with better inhibition abilities were less likely to resort to avoidant coping, while another study found executive deficits to be related to greater disengagement and emotion-focused coping (O'Rourke et al., 2020). Given that appropriate coping strategy and flexibility in coping choice is essential to promote psychological adjustments in daily life (Cheng et al., 2014), executive functioning could serve as a protective factor. While some evidence of this association has emerged for anxiety (O'Rourke et al., 2020), future research should focus on stress regulation more specifically.

Finally, the findings relating to rumination are in line with research indicating that stress responses may depend on the personal abilities to inhibit negative thoughts and worries before or after a stressor. For example, the degree of thought intrusion following a thought suppression task is lower if the individual presents better working memory (e.g., Brewin & Beaton, 2002). Similarly, executive functioning has been reported to moderate the association between a stressful event and subsequent rumination tendencies (De Lissnyder, Koster, Goubert, et al., 2012). A recent review identified inhibition and cognitive (in)flexibility as particularly crucial for the appearance and maintained presence of perseverative cognition (Ottaviani, 2018). In turn, perseverative cognition is known to prolong physiological stress responses (Brosschot et al., 2006), affecting the cardiovascular, autonomic, and endocrine nervous system (Ottaviani et al., 2016). Consequently, the current review has identified several mechanisms that may explain the protective role of executive functioning for acute stress responses, which now require more systematic investigation.

Limitations

A notable finding of the current review is the lack of existing studies focused specifically on the association between executive functioning and stress responses. In addition, sufficient data to perform a meta-analysis was only available for working memory. This lack of statistical power for RVE analyses prevented us from carrying out supplementary moderator analyses. Furthermore, while most studies in qualitative review included sex as a covariate, other exclusion criteria (e.g., smoking, medication use) or relevant covariates (e.g., age time of day) were not consistent across studies. Their results must be interpreted in light of these limitations.

It is also important to discuss overall study quality and risk of bias. The absence of complete descriptions of biomarker analyses across correlational and interventional studies, the inclusion and statistical accounting of important covariates known to impact the cognition-stress relationship (for a review, see Shields, 2020), and the systematic application of manipulation checks of acute stressors represent three major areas of improvement. In addition, two interventional studies presented high risk of bias for the randomization process and the selection of reported results. Therefore, research in the field should pay particular attention to constructing experimental designs and pre-registering data analysis plans.

Nonetheless, the meta-analysis showed very low heterogeneity and did not suffer from publication bias. As a result, the association between working memory and cortisol reactivity appears valid. It is important to note, nonetheless, that although the design of these studies allows for the examination of executive functioning as a predictor of acute stress, these results remain correlational in nature. The combination of both correlational and interventional findings in the current qualitative review contributes greater weight to shed light on the current association of interest.

Implications and future perspectives

In the area of executive functioning and stress regulation, this review has clarified that further research is warranted. Future studies must implement the appropriate design to allow for the determination of causality of this relationship. This implies using an appropriate timeframe between the evaluation of executive functioning and the administration of an acute stressor. Ideally, using longitudinal and executive functioning interventional designs would enable the causality of this association to be established. A key finding from our review is the lack of designs incorporating several facets of executive functioning within one study. Such paucity complicates the comparison of different weights of these facets. While attentional training appears to have been prioritized thus far, researchers must also consider a greater variety of executive functioning facets to allow for a more fine-grained understanding of the role of each particular function. In the same vein, research teams must consider both subjective and physiological outcome measures. Moreover, our conclusions limited to health adults, future studies could focus on comparing these results among clinical populations. Finally, the next research endeavors should consider the role of age-related, cognitive, and behavioral mediators and moderators. The findings highlight the necessity to explore not only the stress regulation strategies that may be indirectly targeted by executive functioning training, but other major variables relevant to the field that were not systematically reported or investigated to this day. Among potential candidates, age, sex, personality, appraisal, coping strategies, and rumination must be at the forefront of future studies. Although scarce at the current moment, the emerging results reveal this avenue of research as promising.

Lastly, the current review holds several implications for future perspectives in healthy individuals. The qualitative and quantitative review identified attentional control and working memory, respectively, as prominent candidates for interventions. Cognitive control training techniques are already implemented within specific therapies, such as Wells and Matthews' (1996) metacognitive therapy for anxiety and depression. Should future research replicate the emerging associations for other facets in community-dwelling populations, health prevention campaigns could incorporate such trainings in order for individuals to learn to regulate their daily stress responses more efficiently. Limiting repeated – and often unnecessary – stress activation to daily events would prevent the cumulative, deleterious effects of allostatic load.

2.5. Conclusion

The results of the current systematic literature review and meta-analysis identified significant relationships between executive functioning and four of the five phases of acute stress, namely anticipation, reactivity, recovery, and habituation. Better attentional control was recurrently identified as being associated with better reactivity and recovery. The meta-analysis of 10 studies also revealed working memory as being significantly associated with less cortisol reactivity in response to an acute stressor. These findings suggest a regulative role of executive functioning for acute stress responses. Future research combining greater diversification in executive functioning facets, physiological and subjective stress outcomes, as well as mediating and moderating mechanisms are required to fully comprehend the precise role played by executive functioning with respect to acute stress responses.

Table 2. Characteristics of the Studies included in the Systematic Literature Review and Meta-Analysis

Study	Sample	Executive Functioning Facets and Tasks	Acute Stressor	Stress Phases and Outcomes	Findings	Quality Appraisal
Almeida (2017)	N=80; M_{age}= 18.85 (1.54); 58.75% female	Attention: Performance score on Multiple Object Tracking	Laboratory: TSST (N=56) vs. informational travel video in the laboratory (N=24)	Reactivity • Salivary cortisol: PEAK - BASELINE • Subjective: Post-TSST tension (Brunel Mood Scale)	Pearson product-moment correlations: Baseline 5-targets MOT performance negatively correlated with post-TSST tension ($r(79)$ = -.25, p=.027); Correlations between baseline EF and cortisol change due to stressor not reported	NHLBI: Fair BIOCROSS: Poor
Almela et al., (2014)	N=65; $M_{age\ women}$= 63.54 (3.66); $M_{age\ men}$= 63.29 (5.21); 53.85% female	Working Memory: Spatial span score and errors on the spatial working memory	Laboratory: TSST	Reactivity • Salivary cortisol: AUC_i • HR: Results not reported	Regression analyses: Curvilinear relationship between cortisol AUC_i and (a) spatial working memory across all participants ($AdjR^2$= .19, ΔR^2= .07, β=−.29, $F(1,54)$= 5.13, p= .028); (b) forward spatial length in women ($AdjR^2$= .18, ΔR^2 = .06, $F_{(1,52)}$= 4.12, p=.048, men: β=.09, p> .05, women: β=.698, p= .013); and (c) backward spatial length in men ($AdjR^2$=.09, $\Delta R2$=.09, $F(1,52)$= 5.97, p=.018, men: β=.38, p= .016, women: β=−.396,p> .1); covariate: sex	NHLBI: Fair BIOCROSS: Fair
Becker & Rohleder, (2019)*	N=33; M_{age}= 24.00 (5.70); 75.75% female	Working Memory: Sum of correctly recalled words from the last three words on the Word List Task	Laboratory: SECPT	*Obtained by email:* Reactivity: • Cortisol and AA: PEAK - POST-EF • Subjective VAS: PRE-SECPT -POST-SECPT Recovery: • Cortisol and AA: LAST - PEAK • Subjective VAS: LAST - POST-SECPT	Pearson product-moment correlations: Non-sig. association between working memory and both reactivity and recovery	NHLBI: Fair BIOCROSS: Poor

Table 2 (continued).

Study	Sample	Executive Functioning Facets and Tasks	Acute Stressor	Stress Phases and Outcomes	Findings	Quality Appraisal
Becker & Rohleder, (2020)*	*N*=81; M_{age}= 21.80 (3.90); 69.14% female	Inhibition: RT and number of errors on Stroop Color-Word Test	Laboratory: SECPT (*N*=69) vs. warm-water control group (*N*=12)	*Obtained by email*: Reactivity: • Salivary cortisol and AA: PEAK – POST-EF • Subjective VAS: PRE-SECPT – POST-SECPT Recovery: • Salivary cortisol and AA: LAST – PEAK • Subjective VAS: LAST – POST-SECPT	Pearson product-moment correlations: Non-sig. association between baseline inhibition and both reactivity or recovery for individuals who underwent the stressor	NHLBI: Fair BIOCROSS: Fair
Fidler (2006)	*N*=98; M_{age} = 24.63 (3.78); 48.98% female	Inhibition: Interference score on Stroop Color and Word Task	Laboratory: Controllable and uncontrollable versions of the PASAT	Reactivity: • DBP, SBP and HR: residual score obtained by regressing mean stress responses on respective baseline mean	Correlations: Non-sig. associations between baseline Stroop interference score and stress reactivity	NHLBI: Good BIOCROSS: Good
Fiocco et al., (2007)	*N*=101; M_{age} = 58.03 (0.42 standard error); 78.22% female	Cognitive Flexibility: Phonetic and Category Fluency total score Working Memory: Forward and Reverse Digit Span scores	Laboratory: TSST	*Obtained within article:* Reactivity: • Salivary cortisol: percentage increase [(5MIN POST-TSST –BASELINE)/ BASELINE] • Subjective: post-stressor stress Recovery: • Salivary cortisol: percentage change [(45MIN POST-TSST –15MIN POST-TSST)/15MIN POST-TSST] *Obtained by email:* Anticipation: • Salivary cortisol: PRE-TSST – PRE-ANTICIPATION Reactivity: • Salivary cortisol: PEAK – PRE-TSST Recovery: • Salivary cortisol: LAST – PEAK	Bivariate correlations (within article): Non-sig. associations between baseline EF and both reactivity and recovery Pearson product-moment (obtained by email): No sig. associations. Category fluency approached significance with quicker cortisol recovery (*r*(101)=.19, *p*=.054)	NHLBI: Fair BIOCROSS: Fair

Table 2 (continued).

Study	Sample	Executive Functioning Facets and Tasks	Acute Stressor	Stress Phases and Outcomes	Findings	Quality Appraisal
Fox et al., (2010)	Original *N*=104; M_{age} = 21.80 (2.90); 0% female; 4 months post-baseline: Laboratory stressor, *N*=82; 8 months post-baseline: Field stressor, *N*=70	Attention: Aware and unaware positive and negative bias scores on the pictorial Visual Probe Task	Laboratory: 5-minute socially-evaluated speech on the need of statistics Examination stressor: "Have I prepared well enough for my exams?"	Reactivity: • Salivary cortisol: AUC_g ; change = 5MIN POST-STRESS – BASELINE;	Pearson correlations: Masked negative bias sig. correlated with AUC_g ($r(80)$= .43, p<.001) to laboratory stressor, and to cortisol AUC_g ($r(68)$= .48, p<.001) to examination stressor Multiple regression analyses: Same bias predicted change in cortisol to laboratory stressor (β=.45, t(82)=3.70, p<.001) and to examination stress (β=.49, $t(70)$=4.0, p<.001); covariates: neuroticism, extraversion, trait and state anxiety, and BDI-II	NHLBI: Fair BIOCROSS: Poor
Goldfarb et al., (2017)*	*N*=38 in original study, *N*=*18* for meta-analysis; M_{age}= 22.11 (3.36); 44.44 % female	Working Memory: Listening Span score	Laboratory: Random assignment to CPT (*N*=20) or warm-water control (*N*=18) session first	*Obtained by email :* Reactivity: • Salivary cortisol: POST-CPT – POST-LSPAN	Pearson product-moment correlations: No sig. associations for participants who underwent control condition first (*N*=18)	NHLBI: Fair BIOCROSS: Poor

Table 2 (continued).

Study	Sample	Executive Functioning Facets and Tasks	Acute Stressor	Stress Phases and Outcomes	Findings	Quality Appraisal
Guevara & Murdock (2019)*	*N*=71; M_{age}= 60.62 (6.19); 74.65% female	Cognitive Flexibility: Perseverative responses and errors, and non-perseverative errors on WCST Inhibition: Z-score (Time and number of errors on Color-Word Test from Delis-Kaplan EF System) Working Memory: Total number of correct responses and largest number of digits correctly on Forward Digit Span Task	Laboratory: TSST	*Obtained within article:* Reactivity: • Salivary cortisol: AUC_g and AUC_i *Obtained by email:* Reactivity: • Salivary cortisol: PEAK - POST-EF Recovery: • Salivary cortisol: LAST - PEAK	Pearson product-moment correlations: Better cognitive flexibility associated with less AUC_g ($r(71)= -.28$, $p<.05$) Linear regression model: Cognitive flexibility did not predict AUC_i ; covariates: age, sex, education, & BMI Mediation model: Lack of indirect effect via ruminations; covariates: age, sex, education level, and BMI Pearson product-moment correlations (obtained by email): No sig. associations	NHLBI: Fair BIOCROSS: Poor
Hendrawan et al., (2012)	*N*=32; M_{age}= 19.13 (1.00); 0% female	Cognitive Flexibility: Total number of words generated from the Letter Fluency Test; Number of categories completed on the WCST Inhibition: RT on the third trial of the Stroop Word-Color Task	Laboratory: TSST	Reactivity: • Salivary cortisol: Average cortisol levels across the three recovery samples • HR and SCL: Average levels across the preparation, speech and mental arithmetic sections.	Multiple regression model: Letter fluency negatively associated with SCL (R^2=.31, β=−.42, p<.05) and cortisol (R^2 = .20, β = -.49, p<.05). Only the latter stayed sig. when adjusting for BMI Pearson product-moment correlations: WCST negatively correlated with SCL (R^2=.31, β=-.42, p<.05)	NHLBI: Fair BIOCROSS: Fair

Table 2 (continued).

Study	Sample	Executive Functioning Facets and Tasks	Acute Stressor	Stress Phases and Outcomes	Findings	Quality Appraisal
Iijima et al., (2018)	*N*=48; M_{age}= 19.70 (1.0); 45.83% female	Attention: Negative Attentional Bias Score on Dot-Probe Task	Daily stressors over six consecutive days	Exposure: • Occurrence of a negative event Reactivity: • Predicting tension-anxiety (Profile of Mood States-Brief Version) at time of stressor by negative event Recovery • Predicting post-stressor tension-anxiety by the negative event	Multi-level analyses: Attentional bias moderated reactivity but not recovery. Compared to individuals with lower bias scores, those with higher scores (*B*=2.25, *SE*=0.33, *t*=6.76, *p*<.001) showed greater increase in stress-anxious mood during stressful event; covariates: gender, STAI, and current activity pleasantness Multiple regression analyses: Attentional bias did not predict the frequency of negative events	NHLBI : Fair BIOCROSS: Good
LeMoult et al., (2019)*	*N*=30 healthy individuals vs. 22 patients; M_{age}= 29.27 (10.34); 60% female	Working Memory: Negative and Neutral Reading Spans scores	Laboratory: TSST	*Obtained within article and by email:* Reactivity: • Salivary cortisol: PEAK – BASELINE Recovery: • Salivary cortisol: LAST – PEAK	Multi-level analyses and Pearson product-moment correlations: No sig. associations between reading spans and both cortisol reactivity and recovery; no covariates as they were not predictive of cortisol response	NHLBI: Fair BIOCROSS: Poor
Lin et al., (2020)	*N*=39; M_{age}= 21.92 (2.08); 0% female	Updating: Accuracy and RT on 2- and 3-back Task	Laboratory: TSST	Reactivity: • Salivary cortisol: percentage increase [(PEAK – BASELINE)/BASELINE]	Bivariate correlations: Sig. association between 2-back RT and reactivity (*r*(39)= -.37, *p*=.020). Hierarchical regression model: 2-back RT sig. predicted reactivity (*β*= -.38, *t*= -2.18, *p*=.037); covariates: age and neuroticism	NHLBI: Fair BIOCROSS: Poor

Table 2 (continued).

Study	Sample	Executive Functioning Facets and Tasks	Acute Stressor	Stress Phases and Outcomes	Findings	Quality Appraisal
McHugh et al., (2010)	Study 1: *N*=35; M_{age}= 21.90 (4.60); 51.43% female Study 2: *N*=65; M_{age}= 23.80 (7.70); 52.31% female	Attention: Threat attentional bias on Dot-Probe Task	Laboratory: PASAT (study 1) and CPT (study 2)	*Obtained by email:* Reactivity • Salivary cortisol: POST-STRESS – POST-EF	Pearson product-moment correlations: No sig. associations in either study	NHLBI : Fair BIOCROSS: Fair
Mehta (2012)	*N*=360 adults M_{age} not reported 50.00% female	Inhibition: Interference RT on Stroop Color-Word Test Cognitive Flexibility: Trail Making Test B/A ratio	Laboratory: Stressor composed of Stroop interference, memory, and tracking tasks	Reactivity: • DBP, SBP, HR, HRV (LF-HRV, HF-HRV, LF/HF ratio): residual change score from baseline to average levels across three tasks Recovery: • DBP, SBP, HR, HRV (LF-HRV, HF-HRV, LF/HF ratio): residual change score from baseline to average recovery levels	Hierarchical regression model: After a Bonferroni correction, better inhibition was a positive predictor of immediate LF- (*B*=.18, *p*=.040; covariates: sex, education, and perceived threat and control) and HF-HRV (*B*= .21, *p*=.020; covariates: education and perceived threat) recovery, and delayed HF-HRV recovery (*B*=.21, *p*=.020; covariates: education and perceived threat)	NHLBI : Fair BIOCROSS: Good

Table 2 (continued).

Study	Sample	Executive Functioning Facets and Tasks	Acute Stressor	Stress Phases and Outcomes	Findings	Quality Appraisal
Morrison (2014)	*N*=105; M_{age}=18.04 (0.20); 62.90% female	Attention: Orienting threat bias on Modified Probe Detection Task; Threat disengagement bias on Posner Spatial Cueing Task; Response latencies on Attention Network Test Inhibition: Antisaccade Task RT and accuracy	Laboratory: TSST	Reactivity: • Salivary cortisol: peak cortisol; residualized change score (peak cortisol after covarying baseline cortisol)	Bivariate correlations: No sig. associations between EF and peak cortisol Hierarchical multiple regression model: Interaction between Antisaccade RT and threat disengagement was positive predictor of cortisol reactivity (β=.90, t=3.43, p=.001); covariate: sex (not age as it did not correlate with cortisol)	NHLBI : Fair BIOCROSS: Good
Otto et al., (2013)*	*N*=56 in original study, *N*=20 for results for meta-analysis; M_{age}= 25.65 (7.33); 55% female	Working Memory: Automated Operation Span score	Laboratory: CPT (*N*=20) vs. control room-water group (*N*=36)	*Obtained by email*: Reactivity: • Salivary cortisol: POST-CPT – PRE-CPT	Pearson product-moment correlations: No sig. associations for individuals who underwent the stressor	NHLBI : Fair BIOCROSS: Poor

Table 2 (continued).

Study	Sample	Executive Functioning Facets and Tasks	Acute Stressor	Stress Phases and Outcomes	Findings	Quality Appraisal
Panganiban, (2013)	*N*=92; M_{age} not reported; 61.96% female	Inhibition: Proportion of stop responses on the Stop-Signal Task; RT difference between Stroop Task congruent and incongruent trials Cognitive Flexibility: Shift cost on Number-Letter and Local-Global Tasks Updating: Proportion of correctly recalled letters or words on the Letter Memory and Keep-Track Tasks	Field stressor: Negative feedback messages during unmanned aerial vehicle simulation vs. no feedback control group	Reactivity: • Retrospective (post-stressor) self-reported distress while performing the task, using the Dundee Stress State Questionnaire	Correlations: In low task load, better updating associated with less distress ($r(92)= -0.06$, $p<.05$) Hierarchical multiple regression model: Controlling for stress group, better inhibition (β = -.18, p <.05) and worse updating (β =.26, p <.01) predicted less distress, threat appraisal, and situational uncontrollability over the stressor	NHLBI: Fair BIOCROSS: Good
Pilgrim et al., (2010)	*N*=25; M_{age}= 23.00 (4.00); 56.00% female	Attention: Attentional engagement and disengagement scores on Posner Spatial Orienting Paradigm for stress- neutral and positive-neutral material	Laboratory: modified TSST	Reactivity: • Salivary cortisol: AUC_i; percentage increase: [(PEAK – PRE-TSST)/PRE-TSST] • DBP, SBP & HR: Results not reported	Pearson product-moment correlations: Sig. correlation between stress-neutral engagement scores and AUC_i ($r(25)= -.44$, p=.03, r^2= .19); covariates: sex and past income Multivariate analyses: Sig. difference between slow- and fast- engagers. 81% of the latter showed cortisol increase against -3% decrease in slow engagers ($t(23)=2.64$, p=.02, d= 1.07)	NHLBI: Fair BIOCROSS: Poor

Table 2 (continued).

Study	Sample	Executive Functioning Facets and Tasks	Acute Stressor	Stress Phases and Outcomes	Findings	Quality Appraisal
Quaedflieg et al., (2019)*	N=112 in original article, 52 for meta-analysis; M_{age}= 22.32 (2.81); 49.09% female	Working Memory Total score on Forward and Backward Digit Span Task	Laboratory: MAST (N=56) vs. control (N=56)	*Obtained by email:* Reactivity: • Salivary cortisol: PEAK – PRE-MAST Recovery: • Salivary cortisol: LAST – PEAK	Pearson product-moment correlations: No sig. associations for individuals who underwent the stressor	NHLBI: Fair BIOCROSS: Poor
Quinn et al., 2019	N=39; M_{age}= 18.58 (0.60); 69.20% female	Updating Number of errors on Affective 2-Back Task	Laboratory: TSST (N=23) vs. control task (N=16; discussion about movie, novel or trip and arithmetic task)	Reactivity: • Salivary interleukin-1b, interleuking-6, and tumor necrosis factor-α: POST-STRESS - BASELINE	Correlations: No sig. association between baseline updating and change in physiological measures Multiple regression model: Baseline updating did not sig. predict reactivity; covariates: gender and family income	NHLBI: Good BIOCROSS: Good
Roelofs et al., (2007)	N=20; M_{age}= 22.10 (4.20); 90.00% female	Attention Angry and happy Attentional Bias Scores on Emotional Stroop	Laboratory: TSST	Reactivity: • Salivary cortisol: [(PEAK – PRE-TSST LOWEST VALUE)/PRE-TSST LOWEST VALUE] • DBP, SBP and HR: Results not reported	Two-way repeated measures ANOVA: Compared to low responders, high responders showed negative (avoidant) attentional bias to threat at baseline (F(1,18)= 5.55, p<.005, n^2= 0.24); covariates: gender, menstrual cycle, & oral contraceptives	NHLBI: Fair BIOCROSS: Poor

Table 2 (continued).

Study	Sample	Executive Functioning Facets and Tasks	Acute Stressor	Stress Phases and Outcomes	Findings	Quality Appraisal
Roos et al., (2017)*	N=97, 51 with full results in stress group; M_{age} not reported; 52.94% female	Inhibition: Stop-Signal RT on Stop-Signal Task	Laboratory: TSST (N=58) vs. quietly reading a magazine (N=39)	*Obtained by email*: Anticipation: • HR and HF-HRV: PREAPARATION – BASELINE Reactivity: • HR and HF-HRV : TSST – BASELINE	Pearson product-moment correlations: Sig. positive correlation between inhibition and HF-HRV anticipation (r(51)=.44, p=.001) for individuals who underwent the stressor	NHLBI: Fair BIOCROSS: Good
Sanchez et al., (2017)	N_{total}=30 adults; 22 adults with minimal depressive symptoms; M_{age}= 23.45 (4.23); 86.36% female	Attention: Attentional engagement and disengagement scores on an Attentional Engagement-Disengagement Task	Laboratory: Speech-giving on why one is a good friend	*Obtained by email:* Reactivity: • HRV (RMSSD) and tension VAS: STRESS – PRE-STRESS Recovery: • HRV (RMSSD) and tension VAS: POST-STRESS – STRESS	Pearson product-moment correlations: Time to disengage from happy faces (r(22)= -.50, p=.017) and to engage with both disgusting (r(22)= -.60, p=.003) and sad faces (r(22)= -.55, p=.008) was negatively associated with tension reactivity Engagement time with disgust stimuli was negatively associated with tension recovery (r(22)= -.49, p=.021)	NHLBI: Fair BIOCROSS: Poor

Table 2 (continued).

Study	Sample	EF	Stressor	Stress Phases and Outcomes	Findings	QA
Schwerdt-feger & Derakshan, (2010)*	*N*=70; M_{age}= 33.51 (10.60); 50% female	Attention: Engage-ment and scores for angry and happy faces on Spatial Cueing Task	Laboratory: Speech task in front of camera and experi-menter	*Obtained within article:* Recovery: • HF-HRV: difference from baseline *Obtained by email*: Anticipation: • HF-HRV and RMSSD: PREPARATION PERIOD – POST-EF Reactivity: • HF-HRV and RMSSD: TASK – POST-EF Recovery: • HF-HRV and RMSSD : RECOVERY – SPEECHTASK	*Obtained within article:* Correlations: No significant association between engagement or disengagement for angry faces and HF-HRV recovery Stepwise hierarchical regression model: Disengagement from angry faces negatively predicted HF-HRV reactivity (vagal withdrawal; β= -.27, r_p = -.27, *T* = -2.18, $p < .05$); covariates: age, sex, caffeine, and smoking *Obtained by email:* Pearson correlations: Sig. association between disengagement from angry and change in anticipatory HF-HRV ($r(70)$= -.26, p=.029) and RMSSD ($r(70)$=-.28, p=.021). More time to disengage associated with less HRV change during anticipation	NHLBI: Fair BIOCROSS: Good
Xin et al., (2019)*	*N*=54; M_{age}= 22.57 (1.67); 35.19% female	Inhibition: Proportion of error on no-go trials in the Go/No-Go Task	Laboratory: TSST	*Obtained within article:* Exposure: • Recent stressful life events Reactivity: • HR and HRV (RMSSD and HF-HRV): MEAN-TSST – BASELINE • Salivary cortisol: PEAK – BASELINE *Obtained by email:* Reactivity: Identical to above Recovery: • HRV: RECOVERY – TSST • Salivary cortisol: LAST – PEAK	Independent samples T-tests: Participants with high and low EF did not differ in recent life events Moderation: In participants with low – not high – inhibition, inhibition moderated relationship between recent life events and change in RMSSD (t=2.79, p=.008, 95% CI [0.75, 4.59]), and HF-HRV (t=2.74, p=.009, 95% CI [32.28, 210.28]); covariates: sex & neuroticism Pearson correlations (obtained by email): Sig. associations between inhibition and cortisol reactivity ($r(54)$=.42, p=.001), and recovery ($r(54)$= -.39, p=.003)	NHLBI: Good BIOCROSS: Poor

Note. * indicates study included in the meta-analysis; AA = Alpha-amylase; $AUC_{g/i}$ = Area under the Curve from the ground/increase; BIOCROSS = Quality Appraisal Tool for Cross-sectional Studies using Biomarker Data; BMI = Body Mass Index; CPT = Cold Pressure Test; DBP = Diastolic Blood Pressure; HF = High Frequency; HR = Heart Rate; HRV = Heart Rate Variability; LF = Low Frequency; *M* = Mean; MAST= Maastricht Acute Stress Test; *N* = Number of participants; NHLBI = National Heart, Lung, and Blood Institute; PASAT = Paced Auditory Serial Addition Test; *RT* = Reaction Time; RMSSD = Root Mean Square of Successive Differences; SBP = Systolic Blood Pressure; Sig. = Significant; SCL = Skin Conductance Level; SECPT = Socially-evaluated Cold Pressure Test; STAI = State-Trait Anxiety Inventory; TSST = Trier Social Stress Test; VAS = Visual Analog Scale; WCST = Wisconsin Card Sorting Task.

Table 3. Characteristics of Interventional Studies included in the Systematic Literature Review

Study	Sample	Intervention	Acute Stressor	Stress Phases and Outcomes	Findings	Risk of Bias
Attention						
Baert et al., (2012)	*N*=28; M_{age}= 26.70 (6.60); 59.38% female; Training: *N*=14 Active CTRL: *N*=14	Training: Six-day at-home Computerized Dot-Probe Training to disengage from negative stimuli and simultaneously engage with positive stimuli (dot replaces the happy faces on 90% of trials) Active CTRL: Same task, cues, and number of trials, *without* modification of the contingency	Laboratory: Mock job interview ahead of a real interview	Reactivity: • HRV (RMSSD, LF, HF, LF/HF Ratio): comparing baseline to measures from preparation to speech completion • Subjective: retrospective Tense VAS during stressor Recovery: • HRV (RMSSD, LF, HF, LF/HF Ratio): comparing measures during baseline and follow-up post-stressor	ANOVA: Time*Group not sig. for physiological or subjective reactivity. Stress increased regardless of group Paired samples t-tests: sig. increase of RMSSD in training ($t(13)$=2.46, p=.03, d=30); sig. increase in LF/HF ratio in CTRL ($t(12)$= 2.54, p=.03, d= 0.26) compared to training ($t(13)$=1.59, p=.14); further increase in LF units and decrease of HF units during recovery in CTRL, compared to no change in training group	RoB: Some concerns BIOCROSS: Poor
Higgins & Hughes (2012)	*N*=64; M_{age}= 20.34 (3.39); 100% female; Training: *N*=34 Active CTRL: *N*=30	Training: 19-minute lab-based Computerized Anti-Negative Dot-Probe Task Training, inducing bias *away* from negative stimuli Active CTRL: Same task, inducing bias *towards* negative stimuli	Laboratory: Six-minute speech task in front of microphone	Reactivity: • DBP, SBP, and HR: mean physiological levels during stressor Recovery: • DBP, SBP, and HR: mean physiological levels after stressor	Repeated measures ANOVA: no main effect of group on DBP, SBP or HR ANOVA: For SBP, group*time* neuroticism interaction. In training group, participants high on neuroticism showed normal SBP following intervention. Those low on neuroticism showed higher reactivity. In CTLR, participants with high neuroticism had more pronounced responding to stressor, while those low on neuroticism had normal response.	RoB: High BIOCROSS: Poor

Table 3 (continued).

Study	Sample	Intervention	Acute Stressor	Stress Phases and Outcomes	Findings	Risk of Bias
Pilgrim et al., (2014)	*N*=56; M_{age} not reported; 53.57% female; Masked: *N*=18, Supraliminal: *N*=18, Active CTRL: *N*=20	Masked: 3-day (30-45min) lab-based Computerized Spatial Cueing Paradigm Training, dis-engaging attention from threat stimuli while engaging with positive stimuli, with mask presented after 17ms of facial cue Supraliminal: Same training without mask, Active CTRL: Same facial stimuli but no attentional shift required	Laboratory: TSST	Reactivity: • Salivary cortisol and AA: AUC_g and AUC_i	ANCOVA: No group differences in cortisol AUC_g ANCOVA: Higher cortisol AUC_i in masked (*p*=.015, CI [1.33, 11.42]) and supraliminal (*p*=.008, *CI* [2.07, 12.81]) groups relative to controls; Supraliminals showed overall higher AA AUC_i (*p*<.001, CI [4974, 11.25] and AUC_g than CTRL (*p<.001*, CI [5516, 17.68)], and higher AUCi (*p*=.002) and AUC_g relative to masked (*p*=.013) Hierarchical multiple regression model: Training group (*β* = 7.44, *t*=3.45, *p*=.01) and baseline attention*group interaction (*β* = -.13, *t*=-2.24, *p*=.03) sig. predicted cortisol AUC_i (but not sAA); covariate: BDI-II Simple slope analyses: Training increased reactivity in those with high – not low – attentional control	RoB: High BIOCROSS: Fair
Pilgrim et al., (2017)	*N*=69; M_{age} not reported; 60.87% female; Spatial cueing: *N*=16, Dot-probe: *N*=15 Active CTRL: *N*=19, Passive CTRL: *N*=19	Training 1: Five-day (30-45min) at-home Computerized Spatial Cueing ABM Training 2: Dot-probe ABM Active CTRL: Gender Identification Task with no attentional shift required Passive CTRL: daily routine as usual	Laboratory: two TSSTs, two months apart	Reactivity: • Salivary cortisol: AUC_i Habituation: • Salivary cortisol: change in cortisol AUC_i between TSST 1 and 2	ANOVA: Compared to P-CTRL, spatial cueing (*F*(1, 65) = 5.74, *p* = .02, CI [0.53, 5.84]) and A-CTRL (*F*(1, 65) = 4.03, *p* = .05, CI [0.01, 5.09]) showed elevated AUC_i to first TSST; covariate: sex ANOVA: Group*phase interaction. Cortisol reactivity lower in follow-up TSST 2 (compared to TSST 1) in Dot-Probe (*F*(1,42) = 4.72, *p* = .035, CI [-5.198, -0.19]) and Spatial Cueing (*F*(1,42) = 4.71, *p* =.036, CI (-5.19, -0.19)) compared to P-CTRLs; covariate: sex Hierarchical multiple regression model: statistical trend towards baseline attention*group interaction (*β* = -.06, *t*(46)=-1.91, *p*=.06) predicting TSST cortisol reactivity Simple slope analyses: participants with low – but not high – baseline attention presented less cortisol reactivity in both training groups compared to CTRLs (*b* = -3.48, t(46) = -2.54, p = .01)	RoB: Some concerns BIOCROSS: Fair

Table 3 (continued).

Study	Sample	Intervention	Acute Stressor	Stress Phases and Outcomes	Findings	Risk of Bias
Working Memory Updating						
Quinn et al., (2014)	*N*=59; M_{age}= not reported; 44.07% female; Affective Training: *N*=23 Neutral Training: *N*=23 Affective CTRL: *N*=23	Affective training: One-session (35min) lab-based Adaptive N-Back Task (1-, 2-, 3-, or 4-back) with affective words (456 trials) Neutral training: Same task with neutral words Affective CTRL: N-Back with simple target recognition	TSST	Reactivity: • Salivary cortisol: POST-TSST – BASELINE	ANOVA: No significant group*time interaction for cortisol reactivity Hierarchical linear regression model: Rumination did not significantly predict cortisol reactivity in the combined training group (*p*=.70) but did in CTLR (β=.78, $t(62)$=4.32, p<.001). At one SD above the RRS mean, participants in the training groups had *lower* cortisol relative to those in the control group (β = −.53, $t(62)$ = −3.77, p< .001); covariates: BDI-II and RRS	RoB: Some concerns BIOCROSS: Fair

Note. AA = Alpha-amylase; ABM = Attentional Bias Modification; $AUC_{g/i}$ = Area under the Curve from the ground/increase; BDI-II = Beck Depression Inventory-II; BIOCROSS = Quality Appraisal Tool for Cross-sectional Studies using Biomarker Data; CTRL = Control group; DBP = Diastolic Blood Pressure; HF = High Frequency; HR = Heart rate; HRV = Heart Rate Variability; LF = Low Frequency; RoB = the Revised Cochrane Risk-of-bias Tool for Randomized Trials; RMSSD = Root Mean Square of Successive Differences; RRS = Rumination Responses Scale; SBP = Systolic Blood Pressure; Sig. = Significant; TSST = Trier Social Stress Test; VAS = Visual Analog Scale.

Section 2.

Exploring the role of executive functioning for stress anticipation, reactivity, and recovery

Chapter 3.

Executive functioning and anticipatory examination stress: investigating the roles of appraisal, coping, repetitive negative thinking, and worry

The current study examined the role of executive functioning in anticipatory stress ahead of university examinations. We investigated the relationship between multiple executive functioning facets (i.e., inhibition, flexibility, updating, working memory, and planning) and anticipatory examination stress, with a focus on the underlying cognitive and behavioral mechanisms (appraisal, coping, repetitive negative thinking, and worry). Undergraduate students (N = 133) completed executive functioning tasks one to three months before the examination session, followed by a series of online questionnaires one week prior to their first examination. None of the executive functioning facets directly predicted anticipatory stress. Among the underlying mechanisms, however, maladaptive coping emerged as a significant mediator between flexibility and anticipatory stress, while worry mediated the relationship between planning and stress. The findings pave the way for experimental research implementing facet-specific executive functioning training and coping-flexibility programs to improve stress regulation and well-being in students.

Reference

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3.1. Introduction

Anticipatory stress is defined as the activation of physiological and subjective responses after being informed about a future stressful situation, ahead of its actual occurrence (Engert et al., 2013). Anticipating a stressful situation can cause similar reactions to those experienced when confronted with the stressor, such as negative mood, cardiovascular activity increases, and cortisol release (Mikolajczak et al., 2008; Waugh et al., 2010). In the context of academia, examination stress exemplifies this phenomenon perfectly.

Throughout their university career, students face a wide range of stressors, including academic, financial, and health constraints (Talib & Zia-ur-Rehman, 2012). The examination period, more specifically, is an example of a naturally stressful experience of student life (Stowell, 2003). Specific to the examination period, Folkman and Lazarus (1985) identified four distinct stages to the process, namely anticipation, exam, waiting, and results. The anticipatory stage refers to the phase during which the student prepares for the ambiguous conditions of the exam session, without having presented the exam. Significant increases in both self-reported stress and cortisol levels have been observed in high stress – compared to low – examination periods (Weekes et al., 2006). Academic stress has also been associated with significant changes in physical (e.g., hormone levels, immune function) and psychological (e.g., anxiety, negative mood) health, with an important long-term impact on well-being (for a review, see Stowell, 2003). Given its implications for professional opportunities, the examination period calls into question personal aspects of oneself, such as self-image, personal competence, responsibility or control over the outcome, and uncertainty about success and achievement (Faurie et al., 2016). Anticipatory stress may be impacted by cognitive variables, such as appraisals of the situation, and behavioral factors, such as coping strategies implemented to face the impending stressor.

The role of appraisal, coping, repetitive negative thinking, and worry

The central premise of the Transactional Model of Stress and Coping (Lazarus & Folkman, 1984b) is that stress responses result from a transaction between the individual and the environment; an environment that is evaluated as exceeding the perceived subject's resources and questioning one's well-being is associated with a higher likelihood to generate a stress response. According to this model, stress depends on two processes: appraisal and coping.

During the appraisal stage, one's perception of the situational demands (i.e., primary appraisals) and one's evaluation of his/her resources (i.e., secondary appraisals) lead to different stress manifestations. Students facing an examination may assess their ability to deal with the upcoming stress based on different factors (e.g., previous exam performance, frequency of class attendance, time and amount of studying, and perceived skills in the subject; Ennis et al., 2001). A threat appraisal should arise if the student estimates that the examinations will exceed their abilities to perform well. A perception of lack of control may emerge if individuals judge that they do not have the necessary resources to deal with the examinations (e.g., not having studied enough). Typically, the anticipatory and waiting phases generate the highest levels of threat appraisals (Folkman & Lazarus, 1985). Higher threat and lower self-efficacy have been associated with higher stress in the anticipatory stage (Rovira et al., 2010). In addition, students are more likely to experience positive affect when they perceive themselves as having sufficient resources to control the situation (e.g., after studying; Rovira et al., 2005).

The second phase (i.e., coping) involves the generation and implementation of coping strategies to deal with the event and mitigate the impact of primary appraisals (Lazarus & Folkman, 1984b). In academia, a distinction between engagement-oriented coping (i.e., adaptive) and disengagement-oriented coping (i.e., maladaptive) can be made in terms of repercussions on stress (Bonneville-Roussy et al., 2017). Adaptive strategies include active planning (e.g., planning and studying for the exam), reappraisal (e.g., seeing the positive side of the examination), and seeking social support (e.g., for instrumental and emotion purposes, Carver & Scheier, 1994; Rovira et al., 2005). Maladaptive behaviors include avoidance (e.g., avoiding asking for help), procrastination, denial, and blame (Santor et al., 2020). Folkman and Lazarus (1985) also suggested that different types of coping strategies would be favored according to the examination stress stage under consideration. In the anticipatory phase, individuals showed more active coping (i.e., problem-solving), along with positive reappraisal and seeking social support. It appears that coping strategies may also vary over time. While there does not seem to be fluctuations in disengagement-related strategies (behavioral disengagement, physical disengagement, and self-isolation), students typically endorse higher use of engagement-related strategies (active engagement, information seeking, perseverance, and planning) prior to exams, rather than after finding out their grades (Yih et al., 2020). This pattern of coping strategy choice has shown to be associated with better adjustment to university (Aspinwall & Taylor, 1992). More interestingly, levels of stress during the examination period may persist if the chosen coping strategy is ineffective (Crego et al., 2016; Lazarus & Folkman, 1984b).

A final mechanism involved in academic stress is repetitive negative thinking (RNT), which refers to recurrent and persistent thoughts about problems and experiences encountered by an individual (Segerstrom et al., 2003). This variable encompasses both rumination (repetitive thoughts about the past, often about negative feelings) and worry (repetitive and uncontrollable thoughts about potentially negative future events). Rumination and worry have been associated with prolonged cardiovascular, endocrinological, and neurovisceral activity following acute stressors (Brosschot et al., 2006). Specific to academic examinations, higher anticipatory RNT ahead of an examination is associated with greater negative affect, including depressive and anxious symptoms, as well as general distress (McEvoy et al., 2014). Similarly, worrying has also predicted higher stress symptomatology ahead of examinations (Roussis & Wells, 2008). Empirical findings and theoretical models suggest that appraisals and coping may depend on executive functioning.

Executive functioning

Executive functioning is a higher-order neurocognitive system required for goal-directed behavior (Miyake et al., 2000). The most common facets include inhibition, flexibility, and updating (Miyake & Friedman, 2012). Inhibition consists of preventing previously relevant responses, thoughts, and emotions that may be inappropriate for the current task (Miyake & Friedman, 2012). Flexibility allows for the switching between goals, thoughts, and behavioral strategies in adjustment to changing tasks or environmental demands (Uddin, 2021). As a proxy for flexibility, verbal fluency reflects abilities to access one's lexical repertoire and semantic memory, to generate ideas, and to produce language. Updating allows individuals to monitor incoming information in working memory (i.e., a cognitive system that allows for the temporary maintenance and manipulation of a limited quantity of visual and phonological information; Baddeley, 2012) and to remove no-longer-relevant content (Snyder et al., 2015).

Another essential higher-order executive function tailored to academic coping is planning. This involves predicting the outcomes of actions prior to pursuing skill- or strategy-based goals (Kaller et al., 2008). Planning also acts as a foundation for problem-solving, necessitating the formation of mental models of initial and target states, and the subsequent delineation of action sets aimed at achieving the desired state (Unterrainer & Owen, 2006). Furthermore, it draws upon inhibition, flexibility, and updating (Amunts et al., 2020). While studies have concentrated on effects of stress on executive functioning (for a review, see Plieger & Reuter, 2020), a recent meta-analysis (Grimm et al., 2021) suggested that executive functions may also influence stress reactions to acute stressors.

Executive functioning and anticipatory examination stress

Individuals with higher executive functioning abilities appear to have lower levels of physiological stress reactivity (e.g., heart rate, cortisol levels) and subjective stress responses (e.g., perceived stress, self-reported anxiety) to acute laboratory stressors, compared to those with lower executive functioning (Grimm et al., 2021). For example, individuals with better cognitive flexibility may be more efficient at redirecting their attention away from emotional stimuli toward the task at hand, resulting in lower cortisol reactivity when faced with stressors (Guevara & Murdock, 2020). This implies that elevated executive functioning may directly contribute to fostering more adaptive stress responses to stressful situations.

The studies are scarcer for anticipation. In studies that have investigated this association in the laboratory, inhibition emerged as a significant predictor of increased heart rate variability in anticipation of the stressor, while another study found no link between flexibility, working memory, and anticipatory cortisol (for the review, see (Grimm et al., 2021). Further work is needed for the role of executive functioning in anticipatory stress, particularly on stress-related cognitive appraisals and behaviors.

Executive functioning, anticipatory examination stress, and potential mechanisms

Executive functioning may underlie cognitive and behavioral processes involved during anticipation, namely appraisal, coping, negative repetitive thinking, and worry. Initially, executive functioning could serve as a predictor for how individuals *appraise* these examinations. For instance, deficits in inhibition and working memory have been observed in participants who also negatively appraise heights in a virtual reality setting (Newman et al., 2020). Similarly, in the context of evaluative stress, higher inhibition skills were associated with a more positive appraisal of the stressful situation (Panganiban & Matthews, 2014). Consequently, executive functioning may also play a fundamental role in shaping perceptions of upcoming academic examinations.

Beyond initial appraisals, executive functioning may also be involved in coping choices. Goal-related theories (Hofmann et al., 2012) stipulate that executive functions are fundamental for the setting and pursuit of self-regulatory goals. Consequently, inhibition, flexibility, and updating may be involved in the adaptive implementation of coping and emotion regulation strategies in line with specific goal pursuit (Hofmann et al., 2012; Schmeichel & Tang, 2015). In non-clinical populations, higher inhibition has been significantly associated with lower use of avoidance as a coping strategy and, consequently, lower depressive symptomatology (Nieto et al., 2019; see also Plieger & Reuter, 2020, for an overview). Executive functioning deficits have also been related to greater disengagement (denial, behavioral disengagement, substance use, mental disengagement) and emotion-focused (social support, emotional expression, instrumental support, venting, emotional processing) coping, with coping moderating the relationship between specific executive functioning facets and anxiety symptomatology (O'Rourke et al., 2020). Regarding adaptive coping, the findings are more nuanced, often reporting the absence of a relationship with executive functioning (e.g., acceptance, planning, active coping; (Campbell et al., 2009; O'Rourke et al., 2020). In contrast, activation of brain areas relating to executive functioning in adolescents has been associated with lower use of adaptive coping strategies (Reising et al., 2018). Given the significant importance of coping strategies for perceived stress during the anticipation period, identifying the executive functions that promote more adaptive coping should enable researchers to tailor stress-reducing interventions accordingly.

Finally, executive functioning abilities may serve as a predictor of *anticipatory RNT* and *worry* in the context of upcoming university exams. A number of neurocognitive models have been proposed to explain the underlying cognitive mechanisms to rumination (Wong et al., 2023). For example, the H-EX-A-GO-N model (Habit development, EXecutive control, Abstract processing GOal discrepancies, Negative bias; Watkins & Roberts, 2020) proposes that effective utilization of executive functioning plays a fundamental role in suppressing and/or discarding irrelevant information from working memory. The increased negative thoughts may be caused by the maintenance of negative irrelevant thoughts and a reduced capacity to override habits of rumination in the face of a stressor (Watkins & Roberts, 2020). Supporting this notion, two meta-analytical studies have previously reported significant correlations between executive functioning (inhibition, flexibility, and updating) and rumination (Vălenaş & Szentágotai-Tătar, 2017; Yang et al., 2017). Moreover, longitudinal investigations into executive functioning deficits have predicted an increase in rumination both at a subsequent time point (inhibition specifically; De Lissnyder et al., 2012) and over an extended period (i.e., spanning eight days; Ng et al., 2022).

Regarding worry, enhanced executive functioning has also been linked to reduced trait-based worry (Gustavson et al., 2020), while better attentional control has been associated with a lower presence of intrusive thoughts (Macatee et al., 2016). Interestingly, a reciprocal relationship has also been reported for working memory. Trezise and Reeve (2016) explored the reciprocal influences between the two variables throughout a single day using multivariate latent difference score models. They found that these variables influenced each other iteratively over time: while high worry scores predicted decreases in working memory capacity, reduced working memory capacity also predicted increases in worry.

Thus, while executive functioning may underlie RNT and worry, there is a significant research gap relating to how this relationship arises under stressful conditions. Notably, to the best of our knowledge, no research has explored the role of executive functioning for anticipatory RNT before stressful events. Addressing this gap can provide insights into factors contributing to student stress, inform strategies for managing exam-related stress more effectively, and contribute to developing targeted interventions. Overall, these efforts could promote students' academic success and mental well-being during the challenging examination period and beyond.

Study aims and hypotheses

The current study explores the role of executive functioning in anticipatory stress, in the context of upcoming university examinations. We are interested in the predictive role of several facets of executive functions (inhibition, updating, flexibility, working memory, planning) during the anticipatory period of examinations. Appraisal, coping strategies, RNT, and worry will be explored as potential mechanisms, as these factors may mediate the association between executive functioning facets and anticipatory stress.

The following hypotheses were pre-registered on OSF (https://osf.io/jhr54/). First, we initially expected better cognitive flexibility at baseline to predict lower examination stress one month later (Hypothesis 1; e.g., Guevara & Murdock, 2020). In light of the meta-analysis results conducted since the pre-registration (Grimm et al., 2021), we explored the potential for other executive functioning facets for anticipatory stress. In terms of mechanisms, better inhibition should predict more challenge – as opposed to threat – appraisals of the upcoming examination period (Panganiban & Matthews, 2014; Hypothesis 2). Better inhibition and working memory should also predict more adaptive coping and less maladaptive coping (Nieto et al., 2019; Hypothesis 3). Better cognitive flexibility, inhibition, memory updating, and task-switching should predict less worrying and less anticipatory RNT over the upcoming examination period (Cropley et al., 2016; De Lissnyder et al., 2012; Watkins & Roberts, 2020; Hypothesis 4). In turn, participants who perceive the examination as a challenge, who show less tendencies to worry, and who apply more adaptive coping strategies, should present less stress thereafter. Finally, we explored the precise role of these mechanisms through mediational models investigating the indirect effects between executive functioning and anticipatory examination stress.

3.2. Methods

Participants

A sample of 153 participants were recruited from a second-year undergraduate methodological psychology course at UCLouvain or from announcements on student Facebook groups. The former participated in exchange for course credit, while the latter received a 10-euro compensation. Participants were excluded if they were less than 18 years old, if they were not undergraduate students, or if they were not native French-speakers (or had not acquired the French language before the age of 10). A target sample size of 123 was established prior to data collection, using G*Power software (3.1.9.7) for an estimated power of 0.80 and an estimated mean effect size of $f^2 = 0.15$, to perform multiple regression analyses with 17 predictors (most complete model with age, gender, chronic stress, anxiety, depression, and Covid-related stress as covariates). To limit the impact of potential dropouts, our aim was to recruit approximately 150 participants.

Design and procedure

The protocol was approved by the Saint-Luc-UCLouvain Biomedical Ethics Committee. The study was divided into two phases. At Time 1 (between October and December 2020), students were invited to the laboratory one to three months ($M = 59.76$ days, $SD = 10.96$) before their first January 2021 examinations. They were met by an experimenter, who provided them with written information about the study and the consent form. Participants completed questionnaires – hosted on Qualtrics (Provo, UT) – about sociodemographic information, anxiety, depression, and chronic stress. They were then administered six executive functioning tasks on Inquisit Lab 6.2.2. (except for Verbal Fluency), the order of which was counterbalanced. One week before their January

2021 exam session (Time 2), participants received an email inviting them to complete online questionnaires on Qualtrics. To meet the required word count for submission to the journal, we provide a more detailed description of all measures can be found in the Supplementary Materials.

Measures

Questionnaires

Sociodemographic variables

We collected information regarding the participants' gender, age, and years of education.

Chronic stress

Stress levels within the last month were evaluated using the Perceived Stress Scale (PSS; French version: Bellinghausen et al., 2009). The scale showed good internal consistency with Cronbach's α of .87 at both times.

Anxiety

Anxiety symptomatology was assessed using the Generalized Anxiety Disorder self-report questionnaire (GAD-7; French version: Micoulaud-Franchi et al., 2016). The scale had a good internal consistency (Cronbach's α of .84 and .86 at Times 1 and 2, respectively).

Depression

Depressive symptoms were measured using the Center for Epidemiological Studies-Depression Scale (CESD; French version: Fuhrer & Rouillon, 1989). The scale presented a Cronbach's α of .86 at Time 1 and .91 at Time 2.

Anticipatory examination stress

At Time 2, in anticipation of the upcoming January exam session, anticipatory stress was operationalized as the average of five different items rated on a visual analogue scale ranging from 0 to 10 (inspired by Center for Studies on Human Stress, 2019): (a) perceived stress ("How stressed are you about this exam session?", on a scale from total absence of stress to worse level of stress, Lesage et al., 2012); (b) degree of control ("Do you feel you have some control over this exam session?", on a scale of total absence of control to highest level of control; this item was reversed); (c) capacities ("To what extent do you feel that your skills are being put to the test, in the sense that you feel that certain aspects of your personality or your ability to succeed in your exam session are constantly being called into question?", on a scale of total absence to highest level of being put to the test); (d) novelty ("In light of the upcoming exams, do you need to regularly handle new things?", on a scale of total absence of novelty to highest level of novelty); and (e) unpredictability ("Is there a lot of unpredictability in this exam session for you?", on a scale of total absence of unpredictability to highest level of unpredictability). Cronbach's α for this set of items was .78.

Covid-related stress

In order to potentially control for circumstantial stress relating to the Covid-19 pandemic (i.e., compulsory work-from-home measures were still ongoing in Belgium), we translated the Coronavirus Stress Measure (Arslan et al., 2020) into French and administered it to the participants at Time 2 (Cronbach $\alpha = .84$).

Primary appraisal

The Stress Appraisal Measure (Grimm et al., 2024; Peacock & Wong, 1990) was administered at Time 2 to evaluate primary appraisal of the upcoming examination session. Higher primary appraisal scores correspond to higher perceptions of the event as challenging (as opposed to threatening; for more information, see Supplementary Materials). Cronbach's α was .60.

Coping

The situational version of the BRIEF-COPE (French version; Muller & Spitz, 2003) was adjusted to measure coping strategies implemented ahead of the stressor at Time 2. While the original scale regroups 14 coping categories composed of 2 items each, indices for adaptive and maladaptive coping behaviors based on the approach used by Meyer (2001) were calculated. Adaptive coping corresponded to the average of the scores for active coping, planning, instrumental support, emotional support, emotional expression, positive reappraisal, and acceptance (Cronbach's $\alpha = .82$). Maladaptive coping was operationalized as the average of denial, blame, distraction, substance use, and behavioral disengagement (Cronbach's $\alpha = .60$). Higher scores in both subscales indicate higher use of these respective coping strategies.

Anticipatory RNT

The Ruminative Thinking Questionnaire in anticipation of a stressor was forward- and backward-translated in French (McEvoy et al., 2014). The average score for 18 items represented RNT, with Cronbach's α of .92.

Worry

The Penn State Worry Questionnaire (PSWQ; French version: Gosselin et al., 2001) is a widely used self-report measure designed to assess worry. The sum of all items represents the total score (Cronbach's $\alpha = .94$).

Executive functioning

Complete technical details and specific methodological considerations regarding the executive functioning tasks are available in the Supplementary Materials.

Inhibition

The Stop Signal Task was administered in accordance with recent recommendations (Verbruggen et al., 2019). The Stop-Signal reaction time was automatically calculated through Inquisit Lab using the integration model. The race model was violated for four participants, where the reaction time on Stop-Signal trials was longer than reaction times on Go trials that were successfully inhibited. These were removed from further analyses. All p(respond|signal) were above 0.25 and below 0.75(Verbruggen et al., 2019).

Cognitive flexibility

Flexibility was operationalized using two different tasks. First, we used the Letter-Number Task (Miyake et al., 2000). Trials with response times below 200ms and trials following errors were eliminated. Consequently, the average percentage of trials was 10.62% (SD = 8.06). The outcome was the switch cost, calculated as the difference between average correct response times of switch trials and non-switch trials in the combined block (Friedman et al., 2008). A positive value designates longer time to switch between the two tasks.

In the Verbal Fluency Task (Cardebat et al., 1990), participants provided as many words as possible beginning with the letter P within two minutes. The task outcome was the total number of words produced after removing errors and repetitions.

Working memory updating

In the Letter Memory Task (Friedman et al., 2008), the dependent variable was the proportion of letters correctly recalled across all test trials.

Working memory

The Automated version of the Operation Span Task was administered to participants (Conway et al., 2005), which alternates between two tasks: a letter memory test and a mathematical problem. Following previous recommendations (Unsworth et al., 2005), we removed participants with accuracy of less than 85% on the mathematics problems (N = 1). The key outcome variable is the Operation Span traditional score, which is calculated as the sum of letters correctly recalled across all sets. The maximum achievable score is 75.

Planning

Individuals completed the Tower of London task (Shallice, 1982), in which they were asked to arrange three disks of different colors on three pegs of different lengths.

The outcome was the sum of the scores obtained across all problems, with the maximum being 36.

Data analysis

The dataset is available on OSF (https://osf.io/jhr54/) and all pre-registered data analysis strategy were followed. To ensure higher quality data, we inserted two bogus items (item 15 in CESD at Time 1 and item 14 in the Brief-Cope at Time 2), where participants were instructed to “select response 2”. To avoid the influence of extreme outliers, we examined box plots and Q-Q plots for the executive functioning tasks. Any data ranging at more than three times the interquartile range above or below the first or third quartile, respectively, was identified as extreme outliers (Soveri et al., 2018). Seven individuals represented extreme outliers: Letter Memory Task ($N = 1$), Number-Letter task ($N = 2$), Stop Signal Task ($N = 2$), Tower of London Task (N=1), and Maladaptive Coping ($N = 1$). Removing the outliers changed the results for some models, hence we report the results without them. Scrutinizing the Q-Q Plots, boxplots, and Shapiro-Wilk Tests of Normality revealed that age, years of education, updating, flexibility, planning, and maladaptive coping remained non-normally distributed. Consequently, we ran nonparametric Spearman correlations for these, and all other correlations were parametric (Bravais Pearson’s r). The correlational analyses determined the covariates retained in the regression models.

We ran multiple regression models, with primary appraisal, coping, anticipatory RNT, worry, and examination stress as outcomes. For all models, all six executive functioning facets were entered as predictors, with gender, chronic stress, and Covid-related as covariates. For the last model, we also included the mediating variables mentioned previously. It is important to note that since the measures of chronic stress, anxiety, and depressive symptomatology correlated strongly (i.e., above .60, see Table S1), we decided to maintain parsimony by retaining only chronic stress in the model. In addition, age was also omitted from the final models given the lack of variability in our sample (see Table 4 for descriptives). Sensitivity analyses found that the results remained unchanged when including these variables. The results do change for one model when Covid-related stress is included, which we discuss in the results section. All regression assumptions were verified before results interpretation. The regression standardized residuals were also analyzed to identify extreme cases. Two significant residuals were found in the Maladaptive Coping model. Running the model without these residuals yielded the same outcome, so we present the results with them.

The executive functioning tasks emerged as significant correlates of four potential mediators, which we subsequently included in mediational models using the PROCESS macro (v4.2; Hayes, 2017) on SPSS Statistics 29 (IBM). Mediational models 1-4, with 95% confidence intervals and 5000 bootstrap samples, had adaptive coping, maladaptive coping, RNT, and worry as the mediating variables, respectively. Planning was the independent variable in mediational models 1, 3, and 4, while flexibility (Switch costs in the Number-Letter task) was entered for model 2. For all four models, the executive functioning tasks, gender, and chronic stress were covariates.

3.3. Results

Descriptive statistics

From the initial sample (*N* =153), thirteen individuals were removed from analysis, due to technical issues with the cognitive tasks (*N* = 6), the assumptions of the race model being violated on the Stop Signal Task (*N* = 4), accuracy less than 85% on the Operation Span (*N* = 1), and missing data on the questionnaires at time 2 (*N* = 2). None of the participants failed either of the bogus items. Another seven individuals were removed due to representing outliers. The final 133 participants were aged 18 to 47, 79.70% female, and had acquired between 8 to 22 years of education (see Table 4 for descriptives and Supplementary Materials for gender differences between included and excluded participants).

Table 4. Participant Characteristics and Descriptive Statistics for all Study Variables

	Mean	Std. Deviation
Participant Characteristics		
Age (years)	20.39	4.18
Gender (% female)	79.70	
Years of Education (years)	13.70	1.81
Cognitive Tasks		
Inhibition (SSRT)	184.63	42.77
Flexibility (Switch Cost)	694.86	315.35
Flexibility (Verbal Fluency)	20.51	5.34
Updating (Proportion Correct of Letters Recalled)	0.89	0.13
Working Memory (OSpan Score)	45.19	16.12
Planning (Total Score)	33.95	2.04
Stress-related Outcomes		
Examination stress	5.37	1.55
Chronic Stress	21.09	6.99
Covid-related Stress	15.86	3.99
Mediating Variables		
Challenge/Threat	3.27	0.77
Adaptive Coping	2.65	0.48
Maladaptive Coping	1.68	0.33
Anticipatory Repetitive Negative Thinking	2.95	0.81
Worry	54.43	14.48

Note. These descriptives were conducted on the full sample without outliers (*N*=133); *OSpan* = Operation Span; *SSRT* = Stop Signal Reaction Time.

Hypothesis testing

Hypothesis 1: Executive functioning and examination stress

None of the cognitive tasks demonstrated a significant predictive relationship with examination stress (see Table S2). Greater threat appraisals and anticipatory repetitive thinking significantly predicted higher examination stress, irrespective of Covid-related stress.

Hypothesis 2: Executive functioning and challenge/threat appraisals

Since none of the cognitive facets emerged as significant predictors of challenge and threat (Table S3), no additional mediational model was conducted.

Hypothesis 3: Executive functioning and adaptive and maladaptive coping

There were significant correlations for poorer flexibility (greater switch costs on the Number-Letter task) with lower acceptance of the situation and greater substance use (see Table S4, as well as Table S5 for all correlations). Moreover, higher planning scores were correlated significantly with lower use of instrumental and emotional support (see Table S4).

In the regression models, lower planning scores were found to significantly predict higher choice of adaptive coping (β = -0.20, p = .029; Table S6), while higher switch costs (i.e., lower flexibility) predicted more maladaptive coping prior to the exams (β = 0.27, p = .002; Table S7)[1].

Hypothesis 4: Executive functioning and anticipatory RNT and worry

None of the predictors were significant for anticipatory RNT, hence no further mediational model was tested (Table S8). Regarding worry, planning emerged as a significant, negative predictor of worry (β = -0.14, p = .035; Table S9). However, it is important to acknowledge that Covid-related stress removes the effect for planning when included in the regression model (p = .070).

Mediational models testing

First, the mediation model for planning and adaptive coping did not reveal any significant indirect (β = -.01, 95% CI -0.06 to 0.02), direct (β = -.07, p = .364), or total (β = -.09, p = .268) effects between planning and examination stress. While path a (planning on adaptive coping) was significant (β = -.20, p = .029), path b (adaptive coping on

[1] For the adaptive coping model, the test for the planning score is significant, $F(1,120) = 6.92$, p = .010, R^2 change = .05. For the maladaptive coping model, the test for the flexibility task-switching task is significant, $F(1,120) = 10.91$, p = .001, R^2 change = .07.

examination stress) was not (β = .07, p = .360). Thus, although planning may serve as a significant predictor of adaptive coping, adaptive coping does not significantly mediate the relationship between planning and examination stress.

Second, the mediation model for flexibility and maladaptive coping found that the direct and total effects were not significant, but the standardized indirect effect did not cross zero (β = .06, 95% CI .01 to .12)[2]. Both path a (flexibility on maladaptive coping) and path b (maladaptive coping on examination stress) were significant (see Figure 10A). Hence, maladaptive coping appears to significantly mediate the association between flexibility and anticipatory stress.

Third, the mediation model for planning and anticipatory RNT was not significant. While path b (anticipatory RNT on examination stress) was significant (β = .46, p<.001), this was not the case for path a (β = -.11, p = .169), nor for total (β = -.09, p = .268), direct (β = -.04, p = .603), or completely standardized indirect effect (β = -.05, 95% CI -.14 to .02)[2].

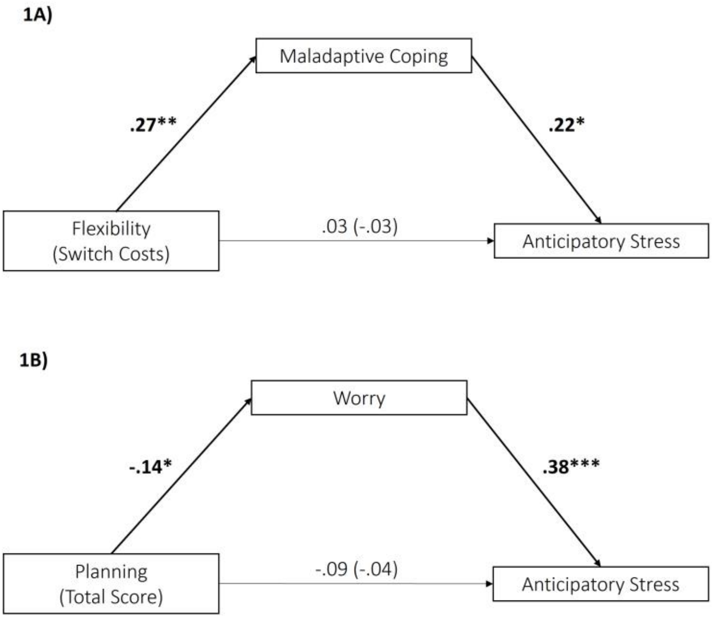

Figure 10. Mediation models: standardized coefficients controlling for executive functioning facets, gender, and chronic stress

Note. 1A) Flexibility, Maladaptive Coping and Examination Stress. 1B) Planning, Worry and Examination Stress. Path in parentheses is the direct effect.

[2] This holds true even after including Covid-related stress in the model.

Fourth, the mediation model between planning and worry showed that while the direct and total effects were not significant, the standardized indirect effect still was (β = -.05), with bias corrected 95% CI ranging from -.12 and -.01 and excluding zero[2] (see Figure Figure 10B)[2]. Consequently, it can be concluded that worry acts as a mediator in the relationship between planning and examination stress.

3.4. Discussion

The current study investigated the role of specific facets of executive functioning as protective factors against anticipatory examination stress within a university setting. Primary appraisal, coping strategies, anticipatory RNT, and worry were explored as mediators of this relationship. It was hypothesized that executive functioning would predict lower examination stress (Hypothesis 1); that inhibition would predict higher levels of challenge (Hypothesis 2); that inhibition and working memory would predict more adaptive and less maladaptive coping (Hypothesis 3); and that better flexibility, inhibition, and updating would predict lower anticipatory RNT and worrying (Hypothesis 4). In turn, participants who perceived the examination as a challenge, employed more adaptive coping strategies, exhibited fewer tendencies to worry, should experience lower levels of examination stress. Most pre-registered hypotheses were not supported by the data. Ultimately, planning and flexibility were most pertinent for mitigating anticipatory stress levels among students ahead of university exams.

Anticipatory Stress

A first important finding is the lack of significant, direct relationship between executive functioning and examination stress, both in the full regression model and mediational models. This contradicts previous theories, work, and meta-analytical efforts (e.g., Grimm et al., 2021; Guevara & Murdock, 2020; Williams et al., 2009) that reported, for example, a protective role of executive functioning for physiological stress reactivity in the laboratory. This role does seem to extend to subjective anticipatory stress measured through self-report questionnaires. The implication of executive functioning may be limited to biological phenomenon such as cortisol (e.g., Guevara & Murdock, 2020). However, executive functioning did impact subjective stress, indirectly, through cognitive and behavioral mechanisms, which we discuss later.

Primary Appraisals

Despite our expectations that individuals with better inhibition and updating abilities would benefit from the inhibition of threat appraisals and more efficient updating of challenge appraisals in working memory (Panganiban & Matthews, 2014), our study did not replicate previous findings. At the neuropsychological level, it is important to consider that primary appraisals may be operating at an automatic level of attentional processing (Schmeichel & Tang, 2015). While reappraisal may involve the inhibition of negative appraisals, the generation and maintenance of non-emotional appraisals in working memory, and the switching between initial and more appropriate appraisals (Schmeichel & Tang, 2015), the immediate primary appraisal may be less under conscious cognitive control. For a more granular approach to executive functioning and appraisal, future research could apply paradigms that capture the generation and modifications of primary appraisals over time, such as ecological momentary assessment.

Adaptive and Maladaptive Coping Strategies

Planning and the Lower Use of Adaptive Coping

A third unexpected finding relates to higher planning predicting lower adaptive coping scores. Although the literature has been contradictory for both clinical and non-clinical samples (Grech et al., 2017; O'Rourke et al., 2020), it was expected that better working memory and inhibition would be associated with more adaptive coping. However, we were unable to replicate this in the sample of university students. Delving further into this finding, it emerged that planning showed significant, negative associations with socially oriented behaviors only, namely lower emotional and instrumental support. Additionally, there were no notable associations found between planning and maladaptive coping mechanisms.

These findings suggest that individuals with higher planning abilities may be more inclined to adopt a self-reliant coping style, taking on stressful situations independently rather than seeking support from others, regardless of how adaptive or maladaptive this approach may be. This reasoning is in line with previous results finding that men – but not women – with better flexibility also demonstrated reduced emotional expression regarding their problems (Rodríguez Villegas & Salvador Cruz, 2015). Moreover, in this study, adaptive coping was not a mediator of the relationship between planning and examination stress. Thus, in turn, this may not necessarily have negative consequences in terms of stress.

These results also show limited evidence of associations between other specific executive functioning facets and adaptive coping in undergraduate students. However, planning is considered a higher-order executive functioning facet that may be reliant on several other facets (Unterrainer & Owen, 2006). Hence, individuals with better planning may also benefit from higher overall executive functioning. Previous research in clinical populations had revealed that lower executive functioning predicted higher use of low-demanding adaptive coping strategies to compensate for the cognitive deficits (e.g., Grech et al., 2017). It is highly likely that the current undergraduate sample presented above-average cognitive functioning, suggesting that they may not need to compensate for a lack of cognitive resources. Hence, these results further reinforce the idea that higher executive functioning leads to more independent coping.

Cognitive Flexibility and the Lower Use of Maladaptive Coping

In contrast to adaptive coping, lower cognitive flexibility (i.e., switch costs) significantly predicted maladaptive coping in anticipation of the exams. Complementary correlations showed significant associations between greater switch costs and lower acceptance of the situation and greater substance use. Maladaptive coping further constituted a mediator of the flexibility-stress association. These findings suggest that greater difficulty in shifting between strategies may cause students to persist in applying maladaptive coping strategies, which may in turn prolong their stress response ahead of the stressor. In support of our findings, *affective* flexibility has previously been associated with spontaneous use of maladaptive coping but not adaptive coping when faced with acute stress (Grol & De Raedt, 2021). Specifically, shifting towards non-affective material in the presence of positive information (i.e., avoidance of emotional material) has been associated with greater use of maladaptive coping. In the context of stress and resilience research, individuals who demonstrate an ability to be flexible in terms of their thoughts, who generate alternate explanations, reappraise efficiently, and accept difficult situations or events also tend to show greater resilience compared to inflexible thinkers (Haglund et al., 2007).

The relevance of flexibility for coping also expands the ongoing discourse regarding the limitations of a binary approach of emotion regulation (e.g., Bonanno & Burton, 2013) and coping (Cheng et al., 2014). An important nuance is that coping choice is highly context specific. The absence of mediation between planning, adaptive coping, and stress links to other theoretical models in the coping literature suggesting that perhaps no individual coping strategy should be considered "adaptive" or "maladaptive" in and of itself; this will depend on the suitability of the choice considering the stressor. In relation to anticipatory academic examinations, flexible switching away from maladaptive coping appears to bring positive consequences for anticipatory stress; while this is less relevant for coping strategies labeled "adaptive". Such coping flexibility has been found to enhance students' perception of control over potential stressors (Freire et al., 2020). As our design prevented us from investigating this, future studies should focus on linking the neurological aspects of cognitive flexibility (e.g., set shifting or switching) with *coping* flexibility (Cheng et al., 2014). Exhibiting variability in – rather than type of – coping strategy choice may be more beneficial for psychological well-being and adjustments to life stressors.

Implications for Planning and Cognitive Flexibility

Implications from these results regarding coping include the potential of cognitive training aimed specifically at flexibility and planning abilities in anticipation of academic and life stressors, but also flexibility in coping choice. For example, universities could implement psychoeducational workshops engaging students to identify coping strategies at play in their own functioning through a case conceptualization, to develop a diverse repertoire of coping strategies to deal with stress, to select adaptive strategies based on the stressor (e.g., more acceptance of the situation), and to disengage from nonadaptive strategies when these reveal to be no-longer useful or beneficial for the student (e.g., learning to disengage from substance use ahead of the exams when this is problematic for studying; based on Philippot and colleagues, *in prep.*).

Repetitive Negative Thinking

In addition to examining behavioral stress mechanisms, our findings replicated prior research on RNT conducted in the academic context (McEvoy et al., 2014). RNT significantly predicted more consequential examination stress. Surprisingly, RNT did not mediate the relationship between planning and examination stress; however, worry did. Participants with higher scores on the Tower of London task reported lower levels of worry leading up to the examinations, which, in turn, resulted in lower self-reported stress. This suggests that effective problem-solving and planning during non-stressful periods are predictive of reduced worry in anticipation of exams. Our results align with previous studies showing associations between executive functioning and trait worry (Fox et al., 2015; Gustavson et al., 2020; Macatee et al., 2016). Several theories may explain why planning is specifically relevant, relating to reducing goal discrepancies and inhibition of habitual tendencies.

Drawing connections to the constructive and unconstructive thought and goal-discrepancy theories (Watkins & Roberts, 2020), RNT are conceptualized as stemming from initial discrepancies between current and desired goals, which crystallize into a habit when repeatedly paired with low mood. In parallel, performance on the Tower of London task requires the identification and maintenance of initial (starting configuration) and goal state (end configuration), as well as the generation of sub-goals and move sequences to attain the latter (Unterrainer & Owen, 2006). Hence, planning requires the ability to program and comprehend the action sequences needed to solve the problem and to mentally rehearse the actions before executing them, which would explain why they may be particularly relevant for reducing goal discrepancies, and RNT thereafter.

A noteworthy observation is the finding being limited to worry. It is important to note that worry and anticipatory RNT overlap as cognitive processes (Zetsche et al., 2018); while the two variables shared similar associations with other variables under investigation, only worry correlated with cognitive tasks in this study (namely flexibility and planning). Previous work has found weak or no associations between specific executive functions and measures of negative thought or affect (Gustavson et al., 2020; Vălenaş & Szentágotai-Tătar, 2017; Yang et al., 2017). Interestingly, another meta-analysis (Zetsche et al., 2018) revealed a small, significant negative correlation between executive control and RNT (i.e., rumination and worry together), but the association with rumination alone was no longer significant after controlling for depression. Our results further bring controversy to this field.

Additionally, in contrast to the RNT questionnaire, the worry items in the current study were *not* adapted to the examination period: worry represented a general tendency to worry (i.e., *trait* worrying). The H-EX-A-GO-N model outlines a two-fold role of executive functioning for rumination. The first involves the monitoring, shifting, updating, or discarding of irrelevant information or thoughts from working memory to alleviate mood (for an overview, see Watkins & Roberts, 2020). The second also highlights how executive functioning facets such as inhibition can override habitual RNT tendencies. Hence, our findings align with this finding, demonstrating that planning, specifically, may stop worrying. Additionally, worry tendencies may inhibit optimal coping (Llera & Newman, 2020). Hence planning may further offset these tendencies by enabling students to focus on effective problem-solving strategies during the examination period, reducing the likelihood of worry. This demonstrates the utility of using both "state" and "trait" measures of RNT, as planning was more relevant for the *habit* of worrying during this anticipatory period. The content of the worrying was seemingly less important than the habit itself. Future studies should incorporate both measures to clarify this effect.

Limitations

Despite the novel findings in this study, there are limitations that must be addressed. Firstly, the study was conducted in 2021 during the Covid-19 pandemic, which may have introduced unique contextual influences on the results. We included a Covid-related stress variable in our study to mitigate potential confounding effects. Although we cautiously conclude that the findings may extend beyond Covid-19 circumstances, it is advisable to replicate the results, especially now that the pandemic-related stress has decreased.

Second, despite two distinct testing phases that allowed for executive functioning to be measured ahead of the examination period, the correlational nature of the study prevents the establishment of causality. Nonetheless, a main strength of this study remains in the consideration of several facets of executive functioning measured using neuropsychological tasks. Thus, future studies should apply experimental designs (e.g., manipulating individual facets) to provide additional evidence for the predicting role of executive functioning.

Third, the study relied on self-report measures for assessing stress levels. Although this approach is interesting for measuring perceived levels of stress, it is possible that the participants may experience difficulties in identifying or reporting their own stress symptoms. Factors such as avoidance or recall bias could influence these self-assessments. Future studies could supplement self-report measures with physiological indicators (e.g., cortisol levels or heart rate variability) to broaden the understanding of the mechanisms at play.

Conclusion

This study examined the role of individual executive functioning facets in anticipatory examination stress. Cognitive flexibility and planning represented protective factors against higher levels of anticipatory stress, through mediations by maladaptive coping and worry. Specifically, better cognitive flexibility predicted lower use of worry, while planning predicted lower maladaptive coping. Ultimately, a comprehensive understanding of these cognitive and behavioral mechanisms could inform the development of flexibility and coping interventions to support students in managing examination-related stress and enhancing overall well-being.

Chapter 4.

Executive functioning and acute stress responses: The role of cognitive appraisals, repetitive negative thinking, and emotion regulation

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Exposure to stress can have significant, negative consequences on long-term health. Among modifiable targets for promoting adaptive stress responses, executive functioning has emerged as a promising candidate. The current study sought to examine the extent to which executive functioning facets (inhibition, flexibility, updating) and working memory capacity played a beneficial role in reactivity and recovery to an acute stressor. Participants completed executive functioning tasks in the laboratory before undergoing either an acute stressor (Maastricht Acute Stress Test, MAST) or its control equivalent (placebo-MAST). Multilevel models were conducted to predict anticipation, reactivity, and recovery to the stressor. For anticipation, poorer flexibility was associated with higher anticipatory blood pressure and skin conductance levels after receiving MAST instructions. Additionally, lower inhibition was associated with higher systolic blood pressure and lower skin conductance levels. For reactivity, lower flexibility was related to greater skin conductance levels during the stressor period compared to baseline. For recovery, poorer flexibility was related to poorer stress recovery, as evidenced by increased systolic blood pressure, mean skin conductance levels, and stress levels after the resting period compared to baseline. Poorer inhibition also predicted worse heart rate recovery. We found no evidence for a significant mediational role of cognitive appraisals, repetitive negative thinking, or emotion regulation. Hence, the study findings identified flexibility and inhibition as important factors for the promotion of adaptive acute stress responses.

Reference

Grimm, E. & Agrigoroaei, S. (2024). Executive Functioning and Acute Stress Responses: The Role of Cognitive Appraisals, Repetitive Negative Thinking, and Emotion Regulation. *In principle proof of acceptance (following Stage 1) in Psychophysiology.* https://osf.io/3hux8. Department of Psychology, UCLouvain.

4.1. Introduction

While stress is a natural phenomenon and an inherent part of life, it also represents a considerable risk factor for both physiological and psychological disorders when its occurrence is repeated and sustained (Schneiderman et al., 2005). An adaptive acute response to a stressful event is denoted by both the reactivity of the physiological systems during the stressor (al'Absi, 2018) and their recovery, namely the prompt return to baseline following stressor discontinuation (Panaite et al., 2015). Over time, however, the prolonged or improper activation of these responses may result in the cumulative wear-and-tear of physiological systems, a phenomenon referred to as allostatic load (McEwen, 1998). The over-release of stress hormones instigates a cascade of cellular events that influence the parasympathetic nervous system, inflammatory processes, as well as lipid and glucose metabolism. Ultimately, this leads to adverse health conditions, such as cardiovascular and autoimmune diseases, as well as mental disorders (e.g., Schneiderman et al., 2005; Yaribeygi et al., 2017). Notably, stress is involved in the onset and/or maintenance of clinical disorders, including anxiety and depression (e.g., Hammen, 2005).

To prevent excessive stress and subsequent stress-related disorders, research has converged on the need for identifying personal, modifiable factors that could be targeted by prevention programs. Among these factors, executive functioning and working memory capacity represent potential resources for promoting adaptive stress responses. Inhibition involves preventing previously relevant responses, thoughts, and emotions that may be no longer relevant or inappropriate for the task at hand. Flexibility allows us to shift from one goal, thought, idea, or perspective to another, as well as to achieve optimal choice in a task, or to optimize the fluidity of our thoughts (Diamond, 2013; Hofmann et al., 2012). Updating facilitates the monitoring of incoming information in working memory and the deletion of content that is no longer relevant to the current task (Miyake & Friedman, 2012). Working memory capacity is "the system responsible for active maintenance and manipulation of information over brief time periods" (McCabe et al., 2010, p. 4).

Given the unity and diversity of executive functions (Miyake & Friedman, 2012; Rodríguez-Nieto et al., 2022), and their intricate relationship with working memory capacity (Engle, 2018; McCabe et al., 2010), it is interesting to examine how they contribute both independently and collaboratively to the orchestration of cognition and behavior. While previous research has focused primarily on the cognitive deficits caused by acute stress (e.g., Kan et al., 2021; Shields et al., 2016), or on the relationship between executive functioning and chronic stress (e.g., Möschl et al., 2022), a recent systematic literature review and meta-analysis (Grimm et al., 2021) revealed that executive functions may reduce subjective and physiological stress responses to acute stressors induced in the laboratory.

Acute Stressor Reactivity and Recovery

Stress reactivity, on the one hand, is defined as the change in physiological and psychological responses when an individual is exposed to a stressful situation. The recovery phase, on the other hand, corresponds to the period following the stressor offset, during which the body attempts to achieve homeostasis and modify physiological activity for a return to baseline. Two major systems are involved in the initial reactivity phase: the immediate activation of the sympathetic-adrenaline-medullary axis and the more delayed hypothalamic-pituitary-adrenal axis release of cortisol (i.e., the primary glucocorticoid stress hormone). The sympathetic system releases epinephrine, norepinephrine, and alpha amylase (Nater & Rohleder, 2009). Heart rate is influenced by both the sympathetic and parasympathetic nervous systems (Malik, 1996; Reyes del Paso et al., 2013; Thayer & Lane, 2000). It is caused by both direct neural innervation and the epinephrine and norepinephrine neuroendocrine activity (Everly & Lating, 2002). Heart rate variability (HRV), a measure of the interval between consecutive heartbeats, represents the ability to respond and adapt to fluctuating stimuli, with lower variability indicating higher stress reactivity (Dimitriev & Saperova, 2012; Kim et al., 2018). Similarly, with both the sweat glands and skin blood vessels being innervated by the sympathetic nervous system, the galvanic skin conductance and blood pressure are also proxies of both sympathetic and parasympathetic activation and autonomous emotional regulation (Hu et al., 2018; Paszkiel et al., 2020; Setz et al., 2010). These stress responses can also be generated in anticipation of the stressor, ahead of actual exposure, in an attempt to prepare the body for incoming threat and to facilitate coping processes (Turan et al., 2015). In parallel to these physiological responses, stressful events can also impact the subjective experience of stress (Calvo & Gutierrez-Garcia, 2016). Subjective stress, defined as the psychological response to a stressor, is often measured through self-reported questionnaires. Items include self-related anxiety and stress, as well as feelings of nervousness or tension.

In the laboratory, acute stress has been induced using validated, standardized stress tasks. These include the Trier Social Stress Test (TSST, social-evaluative stressor, Kirschbaum et al., 1993), the Cold Pressor Test (CPT, physiological stressor with social elements, Becker et al., 2019; Schwabe & Schächinger, 2018), the Paced Auditory Serial Addition Test (cognitive stressor, Gronwall, 1977), and the Maastricht Acute Stress Test (MAST, social and physiological stressor, Smeets et al., 2012). The latter is particularly interesting, as it is intended to be rapid, non-invasive, and less resource-intensive, while combining the social-evaluative and pain elements of the TSST and CPT, respectively. The advantage of these induction methods is that they allow the observation of different stages of the acute stress response, namely reactivity and recovery, which would be otherwise difficult to capture using less controlled paradigms.

Executive Functioning and Acute Stress

Crum and colleagues (2020) recently proposed a stress optimization model that outlines the importance of shifting one's attentional focus away from negative-related stimuli and towards goal-specific information to adjust stress responses. In line with this idea, a systematic review found poorer executive functioning to correlate significantly with subsequent higher reactivity to an acute stressor, as well as poorer physiologically and subjectively return to baseline levels (Grimm et al., 2021). In the meta-analysis, better working memory was associated with lower cortisol reactivity during an acute stressor (Grimm et al., 2021). In specific studies of the review, preconscious biases in attentional control towards threat-related cues tended to enhance cortisol reactivity to an acute stressor (Fox et al., 2010), while the more voluntary control of attention away from negative information towards positive material led to more adaptive stress responses (Schwerdtfeger & Derakshan, 2010). These findings imply that facets of executive functioning may restrict excessive physiological stress activation and promote a faster recovery.

This premise opens a new field of research that motivated our interest in investigating the specific impact of multiple executive functions for these stress phases. Indeed, the primary limitation in the field, currently, lies in inconsistencies revealed in existing associations between executive functioning and acute stress (e.g., Grimm et al., 2021), the need for replication, and the lack of simultaneous consideration of multiple executive subdomains in statistical models for differentiating facet effects. Furthermore, cognitive and behavioral factors such as primary and secondary cognitive appraisals, repetitive negative thinking, and emotion regulation strategies (Grimm et al., 2021) may also be implicated as mediators of the executive functioning-stress relationship.

Cognitive Appraisals, Repetitive Negative Thinking, and Emotion Regulation

Cognitive Appraisals

According to Lazarus and Folkman's (1984) Transactional Model of Stress and Coping, when confronted with a potential stressor, individuals engage in two types of appraisals. Primary appraisals correspond to the preliminary assessment of whether "the encounter with the environment is relevant to his or her well-being" (e.g., centrality, Folkman et al., 1986 p. 992) and whether the event is perceived as neutral, positive, or negative (Lazarus & Folkman, 1984b). If a person rates the event negatively, it is further classified as harmful (i.e., damage or loss has already occurred), threatening (i.e., expecting harm or loss because of the upcoming event), or challenging (i.e., a threat that may be overcome; Carpenter, 2016). Secondary appraisals are assessments of the range of coping options, considering the demands of the situation, available personal resources, and realistic control possibilities (Gaab et al., 2005; Lazarus & Folkman, 1984b). The imbalance between the two appraisal types, in turn, will influence the selection of emotional regulation and coping strategies, as well as the degree of stress reactivity and recovery.

Preliminary associations have been reported regarding the role of executive functioning for cognitive appraisal. Better inhibition, for example, has been associated with lower threat appraisal and stress uncontrollability (Panganiban & Matthews, 2014), whereas working memory has also been negatively associated with threat appraisal (Zandara et al., 2016). Similarly, Xin and colleagues (2020) discovered that participants with lower inhibition showed a negative correlation between exposure to recent stressful events and changes in HRV markers (i.e., blunted changes in Root Mean Square Successive Difference, RMSSD, and High-Frequency HRV) during the TSST. This effect was not reported for the group of participants presenting high inhibition. The authors interpreted the lack of findings for higher executive functioning as the result of these individuals' more flexible and adaptive appraisal of stressful life events, given a better performance of the prefrontal cortex.

Repetitive Negative Thinking

Repetitive negative thinking is defined as recurring, passive and/or uncontrollable thinking that focuses on negative content (Ehring & Watkins, 2008; Segerstrom et al., 2003). Depressive ruminations and worry are two of the most emblematic examples of repetitive thoughts. The former is a response to distress, in which the individual passively and repeatedly focuses on his or her symptoms, as well as their causes and consequences of the latter (Nolen-Hoeksema et al., 2008). Worry, on the other hand, is characterized by a chain of negative thoughts and images that are frequently perceived as uncontrollable (Borkovec et al., 1983; Freeman et al., 2020). Despite a minor difference in temporal focus (one oriented towards the past, the other towards the future), authors agree that they form a larger, multidimensional, and transdiagnostic process known as repetitive negative thinking (Gustavson et al., 2018; McLaughlin & Nolen-Hoeksema, 2011).

In the stress literature, this concept is also referred to as perseverative cognitions (Brosschot et al., 2006). These are representations of the stressor that are activated in a repeated and chronic manner and maintained in working memory despite the stressor no longer being objectively present. A systematic review and meta-analysis on the relationship between perseverative cognitions and stress-related physiological outcomes found that these thoughts exacerbate and prolong physiological stress responses (Brosschot et al., 2006). They impact cardiovascular, autonomic, and endocrine nervous system activity (Ottaviani et al., 2016). Experimental studies have shown that the presence of ruminations or worries after a stressor predicts a greater increase in heart rate, blood pressure, and cortisol levels, as well as a decrease in HRV (Maeda et al., 2017; Ottaviani et al., 2016; Zoccola & Dickerson, 2015).The repetitive negative thinking induction also appears to reduce HRV (Rocha-Oliveira & Zibetti, 2022). In turn, prospective studies have established that repetitive negative thinking and cognitive perseverations are involved in the onset and/or maintenance of emotional difficulties and psychopathology (e.g., Watkins & Roberts, 2020), as well as increased chronic stress, health risk behaviors, and health-related diseases over time (Brosschot, 2010; Brosschot et al., 2006; Clancy et al., 2016; Verkuil et al., 2010).

Interestingly, repetitive thoughts do not systematically have negative implications. According to the processing-mode theory (Watkins et al., 2008; Watkins, 2008), when an individual is faced with a stressful event, he or she may engage in one of two modes of processing repetitive thoughts: the abstract-analytical mode and the concrete-experiential mode. The former corresponds to a generalized and decontextualized mode of processing the event. It prompts the individual to ruminate on the causes, meanings, and implications of an event (e.g., the "why" mode; "why does this always happen to me?" Watkins et al., 2008). Given that this mode requires few cognitive resources, it is favored when confronted with a stressor. This thinking mode is associated with negative outcomes, such as mood deterioration, decreased participation in pleasurable activities, persistence of psychological difficulties, and poor therapeutic efficacy (Nolen-Hoeksema et al., 2008; Tanner et al., 2013; Watkins et al., 2008).

In parallel, one can engage in concrete-experiential repetitive thinking. The latter prompts individuals to focus on event elements that are specific to the situation, on contextual and emotion-related details, and on solution options to deal with the stressor (e.g., the "how" mode; "how can I handle this situation?"; Moberly & Watkins, 2006). Unlike abstract thinking, this mode requires substantial cognitive resources and is associated with improved emotional recovery and problem solving (Bassanini et al., 2014; Harvey et al., 2004).

The re-analysis of datasets containing thinking modes questionnaires (Philippot et al., 2023) has led to the identification of a third mode of thinking: dendritic-creative thinking. This mode involves generating a wide range of new and original ideas that are not necessarily tied to current experiences (Philippot et al., 2023). It embodies flexible thinking, marked by the creation of innovative and original solutions, and does not need to be anchored in the present experience.

Given the effort required for switching towards concrete thinking, executive functioning should play a role in the choice of thought processing mode. In their H-EX-A-GO-N model, Watkins and Roberts (2020) identify executive functioning as a causal contributor to the onset and maintenance of ruminative thinking. Deficits in monitoring, shifting, and updating could cause excessive access to negative information, inciting individuals to continue dwelling on this negative material. In addition, deficits in executive functioning could also prevent individuals from disregarding habitual tendencies to ruminate when faced with difficult situations. Similarly, in a review by Ottaviani (2018), inhibition and flexibility were suggested as two essential facets for stress regulation.

In support of these theories, correlational, experimental, interventional, and longitudinal studies have supplied evidence for executive functioning deficits linked to higher tendencies for repetitive thinking. For example, deficits in flexibility (Cropley et al., 2016; Davis & Nolen-Hoeksema, 2000), updating (Joormann et al., 2011; Meiran et al., 2011), or general executive functions (Whitmer & Gotlib, 2013) have been associated with greater rumination. Meta-analytical approaches have shown significant negative associations with ruminations for both inhibition and flexibility (Yang et al., 2017). Experimental designs using cognitive control training have led to improvements in ruminative tendencies (see Watkins & Roberts, 2020 for a review of existing literature for rumination). With respect to stress, De Lissnyder and colleagues (2012) reported a moderating role of executive functioning, where higher switch costs in the presence of emotional material led to higher tendencies to ruminate in response to daily stressors. However, there has been few research into the link between executive functioning and these modes of thought processing in the context of acute stress.

Emotion Regulation

Emotion regulation is the process of modulating one's cognitive, physiological, behavioral, and emotional responses to meet context-specific goals (Gross, 2014; McRae & Gross, 2020). Gross (1998, 2014) proposes five core elements of emotion regulation after the activation of an emotion-related goal (e.g., reducing negative affect): situation selection, situation modification, attention deployment, cognitive change, and response modulation. Numerous strategies have been studied (see Gross, 2014, for an overview), with considerable research devoted to reappraisal (i.e., cognitive change example) and expressive suppression (i.e., response modulation example). The former consists of modifying cognitive appraisals of the situation, as such to increase positive emotions and/or decrease expressions of subjective negative emotions (Gross, 2014). It is proposed as one of the most effective strategies for emotion regulation, with small-to-medium sized effects on emotions (Webb et al., 2012). The latter refers to the active attempt at controlling the behavioral component of the emotion (i.e., hiding the way they are feeling, Webb et al., 2012). Experimental studies have reported that suppression reduces positive emotions but fails to impact negative emotions (Gross, 2014).

Emotion regulation is increasingly being recognized as an important factor for stress management. The Dynamic Fit Model of Stress and Emotion Regulation (Myruski et al., 2018), for example, has highlighted the concept of "good" and "bad" fit between emotion regulation processes and subsequent stress responses. According to their theory, adaptive strategies can be identified by their successful reduction of "the negative impact of stress" and promoting "emotional well-being and resilience to adversity". When systematically applied in the context of chronic stress, specific emotion regulation strategies may become maladaptive, generating poor mental-health consequences (for example, higher depression in the context of rumination).

Given the overlap in brain regions solicited by executive functioning and emotion regulation, the two are intrinsically linked. According to Zelazo and Cunningham (2007), successful executive function is involved in emotion regulation during (1) the assessment of one's own emotions, (2) the assessment of one's goal state, (3) the generation of strategies to reduce the discrepancy between the two states, (4) the evaluation of strategy efficacy after its implementation, and (5) the learning to switch deliberately and flexibly to other strategies if this one fails to meet expectations. Furthermore, Pruessner and colleagues (2020) propose an overall cognitive control framework, explaining the role of executive functioning for strategy stopping and switching, strategy maintenance, and monitoring. Schmeichel and Tang (2015) posit that inhibition is important for suppressing negative emotions in response to an event, flexibility is required to shift attention away from negative material, and updating is involved in modifying initial emotional appraisals within working memory.

In the context of stress regulation, Crum and colleagues (2020) highlighted the role of executive functioning in appropriate situation selection (i.e., choosing to expose oneself to goal-relevant situations that may generate stress), attentional deployment towards goal-specific material, and the reappraisal of the situation and emotions. Johnson (2009) had previously reported that people who were better at switching from emotional to neutral sets were less frustrated during a stressful anagram task and, moreover, persisted longer on the task. Similarly, Hendricks and Buchanan (2016) found that updating predicted greater negative affect reduction during both reappraisal and expressive suppression. However, research has yet to focus on the role of different facets of executive functioning for emotion regulation during acute stress, a limitation we address with the current study.

Current Study

The goal of this study was to examine the relationship between executive functioning facets and acute stress anticipation, reactivity, and recovery in a controlled laboratory setting (Axis 1). We also investigated the role of cognitive appraisals (Axis 2), repetitive negative thinking (Axis 3), and emotion regulation (Axis 4) in this relationship. A schematic representation of the variables and axes of the study are presented in Figure 11.

Axis 1: Executive Functioning and Acute Stress

This study explored physiological and subjective anticipation, reactivity, and recovery to a stress-inducing laboratory task using the MAST (Smeets et al., 2012). Based on previous findings (Grimm et al., 2021), we expected the three facets (inhibition, flexibility, updating) and working memory capacity to be negatively associated with reactivity (i.e., lower stress reactivity), and positively with recovery indicators (i.e., faster return to baseline; Hypothesis 1).

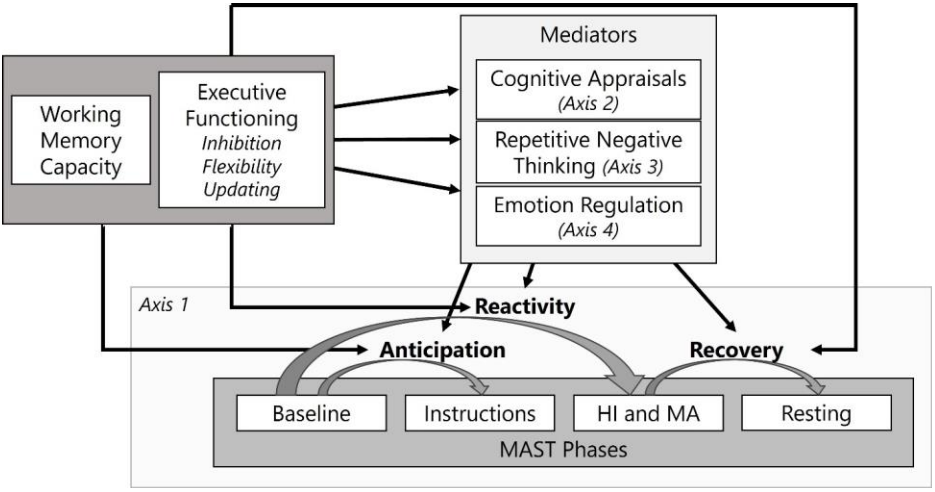

Figure 11. Schematic Representation of the Variables examined in the Current Study

Note. HI = Hand Immersion; MA = Mental Arithmetic.

Axis 2: Cognitive Appraisals

Axis 2 focuses on the role of primary and secondary appraisals in the executive functioning-stress relationship. Based on the literature reviewed (Panganiban & Matthews, 2014; Zandara et al., 2016), it could be postulated that better inhibition and working memory should play a role in keeping more adaptive appraisals in mind in anticipation of the task (e.g., higher perceptions of challenge and control over the stressor; **Hypothesis 2a**). Consequently, this should reduce physiological and subjective activations during the reactivity phase, while predicting a faster return to baseline levels during recovery (**Hypothesis 2b**).

Axis 3: Repetitive Negative Thinking

The objective of Axis 3 was twofold: first, to evaluate whether a mediating role of repetitive negative thinking linking executive functioning facets with stress reactivity and recovery could be replicated. Second, our goal was to differentiate the roles of abstract and concrete modes of processing. We expected better executive functions to be associated with higher concrete-experiential thoughts and lower abstract-analytical repetitive thoughts throughout the stressor (**Hypothesis 3a**). Based on past research (Ottaviani, 2018; Watkins & Roberts, 2020) inhibition and flexibility were hypothesized to be the most relevant facets. We also explore the role of a third construct captured by the scale: creative-dendritic thoughts. This mode consists in having new, original, free, open, creative, and curious thoughts (Philippot, 2019). In turn, we expected to observe lower stress reactivity, as well as a more rapid return to baseline levels after the end of the stressor (**Hypothesis 3b**).

Axis 4: Emotion Regulation Strategies

The final project axis focused on the role of emotion regulation during an acute stressor. We explored the role of each facet for reappraisal and suppression during reactivity. We expected inhibition, flexibility, and updating to predict higher reappraisal and lower suppression (**Hypothesis 4a**). In turn, these were hypothesized to lead to lower stress reactivity and faster recovery following the MAST (**Hypothesis 4b**).

4.2. Method

Study Design

The study was divided into two distinct sessions. In the first session, participants completed a series of online questionnaires at home. In the second session conducted in the laboratory, we administered the cognitive tasks and a series of computer-based questionnaires. Participants then completed the MAST in a separate, designated psychophysiology testing room (Smeets et al., 2012). The study received ethical approval from the UCLouvain-St Luc Biomedical Committee.

Participants

Participants were recruited through social media (e.g., UCLouvain student groups on Facebook), posters placed around Louvain-La-Neuve and Brussels (Belgium), as well as emails sent out to the UCLouvain pool of participants and students at the Faculty of Psychology and Educational Sciences. The target sample size was 85 in the MAST stressor induction group. This was estimated using G*Power 3.1.9.7 (Faul et al., 2007) for a multiple regression model with an estimated moderate effect size f^2 of 0.15 (Cohen, 2013; Selya et al., 2012), an alpha of 0.05, power of 0.80, four predictors (each cognitive task), and four covariates (age, gender, chronic stress, and baseline or reactivity stress to calculate change indices). Based on previous studies (e.g., Becker & Rohleder, 2020), a further 43 individuals were recruited for the control group (placebo-MAST), and 22 more across both groups for estimated participant dropout and equipment malfunction. Recruitment was stopped once we reached 150 participants.

Inclusion criteria comprised being over 18 years of age, having French as one's mother tongue (or having acquired it before age 10), and presenting a Body Mass Index (BMI) between 18 and 30 (Shapiro et al., 1996). Participants were excluded if they smoked (Laborde et al., 2017), consumed more than 25 units of alcohol per week, had a habit of using soft or hard drugs, or presented a current diagnosis or treatment for specific physical disorders (i.e., cardiovascular, endocrine, diabetes; Jennings et al., 1981; Narvaez Linares et al., 2020; Quintana et al., 2016; Shapiro et al., 1996; Shilton et al., 2017). They were also free of current psychiatric diagnosis or treatment (e.g., for depression, anxiety; Quintana et al., 2016; Stone et al., 2021; Vila et al., 2019) and were systematically excluded if they were diagnosed with stress- or anxiety-related disorders (e.g., post-traumatic stress disorder, general anxiety disorder) in their lifetime, if they were undergoing an unusually stressful period (e.g., separation, divorce, examination, current events), or if they had previously been exposed to the MAST (e.g., Gianferante et al., 2014; Stone et al., 2021). These criteria were selected given their known impact on the physiological biomarkers of stress (e.g., for an overview, see Laborde et al., 2017; Labuschagne et al., 2019).

Measures

Online Questionnaires

Sociodemographic and Physical Information

We included items relating to one's age, gender, education, weight and height to calculate BMI, and handedness.

Chronic Stress

The Perceived Stress Scale (Bellinghausen et al., 2009; Cohen et al., 1994) evaluated perceived stress over the last month. The scale was composed of 10 items, four of which require reversing. All items were assessed on a Likert scale ranging from 0 (never) to 4 (very often). The total sum score represented an index of chronic stress. The scale has shown good consistency in previous studies (e.g., Cohen et al., 1994). The scale presented good reliability in this article (α = .86, ω= .87).

Executive Functioning

All cognitive tasks were originally programmed by Millisecond Software and administered on Inquisit 6 (2021). The order of task presentation was counterbalanced across participants.

Inhibition

The Stop Signal Task script was modified to meet recent recommendations (Verbruggen et al., 2019). On each trial, a fixation circle appeared at the center of the computer screen, following which an arrow pointing left or right appeared within a circle. Participants indicated the arrow direction (left or right) using the "D" and "K" keys, respectively. Participants were asked to respond as quickly as possible without waiting for the stop signal to occur, as that would otherwise delay stimuli presentation. On specific trials, participants heard a beep through the headphones, indicating that they must omit from responding. The ratio for signal to no-signal trials was 1:3 and the target response inhibition probability was fixed at 0.5.

The task was divided into four blocks of 64 trials, with arrows pointing to the left or right half of the time. The arrow direction was randomized for each trial. The initial Stop

Signal Delay was set at 250ms and adjusted up or down by increments of 50ms depending upon successful (i.e., increases) or unsuccessful (i.e., decreases) performance. The minimum and maximum delays were 50ms and 1150ms, respectively. Each trial (signal or no-signal) lasted 2000ms, preceded by a pre-trial 500ms pause. A 15-second pause between each block provided participants with prior block results and instruction reminders. The test was preceded by a 32-trial practice block, with 25% signal trials (i.e., 8 signals). Following previous recommendations (Verbruggen et al., 2008), the first trial in each test block was not analyzed. Inquisit 6 (2021) automatically calculated the Stop-Signal Reaction Time using the integration model, as well as the response time for go responses on unsuccessful stop signals. All p(respond|signal) were above 0.25 and below 0.75, as recommended (Congdon et al., 2012; Verbruggen et al., 2019).

Flexibility

Cognitive flexibility was operationalized using the Letter-Number Task (Miyake et al., 2000). Letter-number pairs (e.g., "7G") moving in clockwise fashion to the next box on each new trial, appeared within a 2x2 quadrant. Participants responded to one of two categorization tasks depending on the position of the pair onscreen. If it appeared in the top two squares, participants indicated whether the letter was a consonant ("E" key) or a vowel ("I" key) (i.e., Letter Task). If the pair appeared on the two lower quadrants, participants indicated whether the number was even ("E") or odd ("I") (i.e., Number Task). The task began with two practice blocks, during which the participants completed 32 trials of both tasks, separately. The order of task presentation (i.e., Letter followed by Number, or vice versa) was randomized across participants. Participants completed a combined practice block of 16 trials (i.e., the two tasks simultaneously). The test consisted of 128 trials (64 switch trials, 64 non-switch trials). The stimuli disappeared 150ms after the response if correct and after 1500ms if not. The outcome for this task was the latency shift cost, calculated as the difference between average correct response times on switch trials and non-switch trials in the combined test block. A positive value designated longer time to switch between the two tasks and, therefore, poorer flexibility. Confirming task validity, mean reaction time (in milliseconds) during the switch trials (M = 1550.77, SD = 417.71) was significantly longer than during the repetition trials [M= 970.99, SD = 222.39, $t(137) = 23.54$, $p<.001$]. Similarly, accuracy was better in the switch trials (M = 0.94, SD = 0.05) compared to the repetition trials [M= 0.98, SD = 0.02, $t(137) = -13.58$, $p <.001$].

Working Memory Capacity

The Automated version of the Operation Span Task was administered (Conway et al., 2005), which alternates between two tasks: a letter memory test and a mathematical problem. Three- to seven spans of individual letters were presented on screen. Participants needed to recall as many letters as possible in the correct order using a letter matrix. Between letter trials, simple addition, subtraction, multiplication, or division problems, as well as a possible solution, were presented. Participants chose whether the proposed solution was correct. The practice block comprised (a) four trials of recalling letter spans (with set sizes of two to three in ascending order), (b) 15 trials of the mathematical task, and (c) three trials of the combined tasks (letter set size of two and one math problem). The test block comprised 15 trials, in which five set sizes were repeated three times each. The presentation order of the set sizes was randomized. A math problem preceded each letter. The traditional Ospan score – the sum of all perfectly recalled sets – was used as a proxy for working memory.

Updating

In the Letter Memory Task (Friedman et al., 2008), participants saw a fixation cross for 1000ms, followed by individual letters. For each new letter, they named the last three letters they have seen, which they selected on a letter matrix. Each letter appeared for 2500ms, and each letter set contained five, seven, or nine letters. Three trials (one for each set size) were presented in random order during the practice block. The test block consisted of 12 trials (four per set size), with the order randomized but constrained so that each set size appeared once every three trials. The proportion of letters correctly recalled across all test trials was the independent variable.

Measures throughout the MAST

Subjective Stress

State Anxiety. State anxiety was evaluated using the state scale of the State Trait Anxiety Questionnaire (STAI; Spielberger, 1983, French version: Gauthier & Bouchard, 1993). It included 20 items concerning the current emotional intensity at that moment, using a 4-point Likert scale ranging from 1 (not at all) to 4 (very much). A score was computed by summing the items. Scores can range from 20 to 80, with higher values indicating greater anxiety. The scale shows good internal consistency and test-retest reliability in different samples (Barnes et al., 2002). For the experimental group, internal consistency was good at baseline ($\alpha = .79$, $\omega = .80$), during the stressor phase ($\alpha = .92$, $\omega = .92$), and after the resting phase ($\alpha = .86$, $\omega = .86$).

Stress Item. Based on previous research (Becker et al., 2019; Lesage et al., 2012; Luettgau et al., 2018; Paszkiel et al., 2020), the perceived stress item (“Right now, how stressed do you feel?”) was measured along a visual analog scale ranging from 0 (“not stressed at all”) to 10 (“extremely stressed”).

Stress Appraisal

We administered the Primary and Secondary Appraisal Scale (PASA, Gaab et al., 2005). The wording of the items was modified to match the context of the MAST (e.g., replacing “jury” with “experimenter”). The scale was composed of 16 items on a scale from 1 (totally disagree) to 6 (totally agree). It measured threat (e.g., “This situation scares me”), challenge (e.g., This task challenges me”), self-concept of abilities (e.g., “In this situation I know what I can do"), and control expectancy (e.g., "It mainly depends on me whether the experimenter judges me positively"). We obtained primary and secondary appraisal scores by combining the scores from the first two and last two, respectively. The four factors have shown good internal consistency (e.g., from .60 to .83; Wirtz et al., 2006). For the experimental group, internal consistency was good for threat (α = .71, ω =.76), but poor for challenge (α = .53, ω = .58). Similarly, both self-concept (α = .30, ω = .42) and control (α = .54, ω = .57) showed poor reliability. Merging the two scales into a general appraisal score improved reliability for primary appraisals (α = .70, ω = .73) but not secondary appraisals (α = .47, ω = .55). Given this poor reliability, for results for secondary appraisals will not be interpreted.

Repetitive Negative Thinking Processing Modes

The State Repetitive Thinking Questionnaire (SRTQ; Philippot, 2019) was used to capture state repetitive negative thinking. Individuals rated the extent to which they were having 10 specific thoughts in the preceding minutes, on a scale from 0 ("totally disagree") to 4 ("totally agree"). We focused on the Concrete-Experiential (three items, e.g., "I am focused on what I am concretely experiencing now") and Abstract Evaluative (four items, e.g., "I wonder why I react like this") processing modes. For the experimental group, internal consistency was acceptable for abstract thoughts during the instructions phase (α = .60, ω = .63) but not during the MAST (α = 0.52, ω = 0.57). The concrete subscale presented very poor internal consistency during the instructions (α = .21, ω = .24) and MAST (α = .52, ω = .55). In contrast, the third subscale – creative-dendritic thoughts (three items) – presented good internal consistency during the instructions phase (α = .67, ω = .73) and MAST (α = .73, ω = .77), thus exploratory analyses were conducted with this subscale. This thought, in comparison to abstract-analytical repetitive thinking, is fluid and creative, without the *voluntary* focus of concrete-experiential repetitive thinking (Philippot, 2019; Watkins, 2008).

Emotion Regulation

The Emotion Regulation Questionnaire (ERQ; Gross & John, 2003, French version: Christophe et al., 2009) measured participants' tendencies for reappraisal (six items, e.g., "When I was faced with the stressful situation, I made myself think about it in a way that helped me stay calm") and suppression (four items, e.g., "I controlled my emotions by not expressing them"). The wording was modified to evaluate the strategies implemented during the stressor, ranging from 1 (not at all) to 7 (completely). Previous studies demonstrated adequate internal consistency (reappraisal, α = .76, and suppression, α = .72, Christophe et al., 2009). For the experimental group, internal consistency was good for reappraisal during the instructions (α = .81, Ω = .82) and during the stressor (α = .85, Ω = .85), as well as for suppression during both instructions (α = .71, Ω = .74) and the stressor (α = .68, Ω = .70).

Physiological Stress

The Mindware Mobile Recorder (Mindware Technologies, LTD) was used to measure heart rate, skin conductance, and respiration at a sampling rate of 500 samples per second. Three Electrocardiogram electrodes (45mm, Ag/AgCl, liquid gel, MedCat) were placed according to Mindware Technologies protocols (see https://support.mindwaretech.com/training/): one on the right collarbone and two on the last two ribs on both sides. Respiration was also measured using a belt. In line with the Society for Psychophysiological Research Ad Hoc Committee on Electrodermal Measures (SPRAHCEM, 2012), electrodermal activity was measured using disposable finger electrode strips (Ag/AgCl, MedCat) placed on the distal phalanges of the left major and index fingers and filled with Isotonic Electrode Gel (0.05 molar NaCl paste, Biopac).

These physiological measures were collected using the BioLab Acquisition Software (V3.4.1). Systolic and diastolic blood pressure were event-based, measured using the oscillometer method with the Omron M6 Comfort (HEM-7360-E, Omron Healthcare Co., Ltd; for more information see Topouchian et al., 2014) in sitting position (Shapiro et al., 1996). The M6 Comfort took three consecutive 30-second readings then displays the average.

Procedure

General Procedure

The study began with the signing of an informed consent form and the completion of online questionnaires before one's visit to the laboratory. These included sociodemographic questions, as well as validated measures evaluating chronic stress (PSS-10; Cohen et al., 1994). Then, participants came into the lab for a two-hour visit composed of cognitive testing followed by an acute stress induction. Participants took a 10-minute break between the two sessions to allow for acclimatization (Shapiro et al., 1996). They were able to hydrate, use the restroom, and complete a HRV screening checklist (Laborde et al., 2017). This questionnaire ensured that participants had avoided alcohol and strenuous physical activity for the previous 24 hours, as well as caffeine, food, and smoking for the last two hours (Jennings et al., 1981; Shapiro et al., 1996). They provided their sleep and waking times and confirmed whether they had adhered to their usual sleep routine (Labuschagne et al., 2019). Participants' weight and height were measured before the stress induction. The lab was windowless, temperature-controlled, and electrically shielded to minimize any influences on psychophysiology measures (Shapiro et al., 1996, SPRAHCEM, 2012).

Acute Stress Induction

Acute stress was induced using the validated Maastricht Acute Stress Test (MAST; Smeets et al., 2012; see Figure 12 for the overall procedure). First, participants relaxed for five minutes (~T-20 to T-15), while heart rate, skin conductance, and respiration were continuously measured. Systolic and diastolic blood pressure were then obtained while participants completed the state items of the STAI (Spielberger, 1983) and a perceived stress item (Becker et al., 2019).

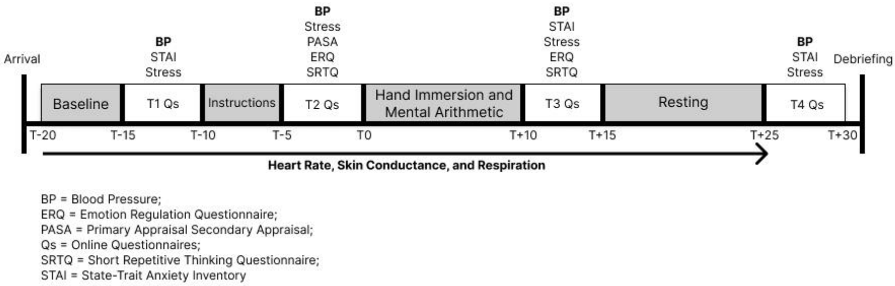

Figure 12. Visual Representation of the Lab Stress Induction Session

The MAST procedure then included an anticipation, stress, and recovery phase. During the anticipation phase (~T_{-10} to T_{-5}, see Figure 12), participants read through the MAST instructions using PowerPoint 2016 (provided by Tom Smeets, Smeets et al., 2012) and were offered the possibility to ask questions. Then, they completed the stress item, as well as questionnaires evaluating primary appraisal, emotion regulation, and repetitive thinking modes. During the *stress* phase (T_0 to T_{+10}, see Figure 12), participants alternated immersing their right hand in ice-cold water and performing a mental arithmetic task (serially subtracting 17 from 2043). Water and arithmetic trials were exactly 90 and 45 seconds, respectively. The experimenter wore a white lab coat and maintained a neutral attitude. A video camera was also placed in front of the participant to record their facial expressions. Participants were informed that their facial expressions throughout the MAST would be analyzed by a research team. Following the initial 10 minutes of the MAST, participants completed the questionnaires again (see Figure 12), and blood pressure was measured once more.

Upon completing the scales, participants were informed that the task was finished and were given a 10-minute recovery phase to relax (~T_{+15} to T_{+25}, see Figure 12). They then completed the STAI and stress items, and we measured their blood pressure. Participants were fully debriefed about the study and were financially compensated with 20 euros.

For a manipulation check, a control group took part in a modified version of the MAST (Placebo-MAST, Smeets et al., 2012). Participants placed their hand in lukewarm water and performed a simple counting task at their own pace. All elements of evaluation (white lab coat, camera, or negative feedback for errors in calculations) were removed.

Data Analysis Plan

Data Cleaning and Processing

Cognitive Tasks

Data cleaning for the executive functioning tasks followed individual task recommendations. For the flexibility task, trials with response times below 200ms and trials following errors were eliminated (Friedman et al., 2008). Regarding the inhibition task, we verified whether the race model was violated (i.e., where the reaction time on Stop Signal trials was numerically longer than reaction times on Go trials that are successfully inhibited), and that all p(respond|signal) were above 0.25 and below 0.75 (Verbruggen et al., 2019). In line with previous recommendations (Unsworth et al., 2005), participants with mathematical problem accuracy scores below 85% on the Operation Span task were also excluded from analyses.

Physiological Data

Heart rate, HRV, and electrodermal activity were analyzed using Mindware Technologies HRV Analysis Software (V3.2.11.). We selected the multi-events option to analyze heart rate between for each phase (see Figure 12): Baseline (T1: between baseline onset and T1 questionnaires), Instructions (T2: between instructions onset and T2 questionnaires), Hand Immersion and Mental Arithmetic Task (T3: between the onset of the stressor tasks and T3 questionnaires), and Resting (T4: between resting phase onset and T4 questionnaires).

Heart Rate and HRV

The Mindware Technologies HRV software allowed for the calculation of R-R intervals. The Very Low Frequency (VLF) Band (Hz) was set between 0.003 and 0.040, the Low Frequency (LF) Band (Hz) between 0.04 and 0.12, and the High Frequency/RSA Band (Hz) between 0.12 and 0.40 (see Task Force recommendations, 1996). The minimum and maximum heart rates were set at 40 and 200bpms, respectively. Each of the three phases were divided into 60-second epochs, where any segments that are less than 30 seconds were not deemed fit for analysis. In addition, any segment for which the respiration power (in volts^2, as recorded through the respiration belt) fell outside the recommended LF and HF Bands were not considered for analysis (Berntson et al., 1997). Each segment was screened for peak artifacts (e.g., incorrectly identified peaks, missing heartbeats, or unusable peaks due to movement), which, on a case-by-case basis, were deleted. Depending on the within-software recommendations, a mid-beat was inserted to correct for these deleted artifacts. Following sufficient agreement between the two raters, the first author carried out the remaining data visualization and modification. We averaged heart rate and HRV values over each respective segments, for each phase.

Skin Conductance Levels

Electrodermal activity was analyzed using the Mindware Technologies EDA software, version 3.2.9., similarly to heart rate. The Event Related Skin Conductance Minimum Response Latency was set at one second and the maximum at three seconds from the event (Levinson & Edelberg, 1985). The threshold level in μSiemens to detect a skin conductance response was set at 0.05 (SPRAHCEM, 2012). A constant rolling filter of 500 data points per block was applied to smooth the EDA signal and we performed a visual inspection of the segments. Artifacts such as subject movement and respiration were identified and edited out (e.g., using the spline function of the software). We calculated mean skin conductance levels for the four phases.

Data Analysis

Screening and Removal of Outliers

All data analyses were conducted on RStudio and SPSS. Data and scripts are available to readers upon request. We checked for normality in distribution for all predictor and outcome variables. We examined the standardized residuals from the regression analyses using the Q-Q plots. Any significant outliers were removed from the respective analyses and the models were reanalyzed without them.

Stress Induction Verification

For all stress indicators (physiological and subjective), we used a repeated measures ANOVA with condition as between-subject variable (MAST vs. placebo-MAST) and time as a within-subject variable (baseline, instructions, hand immersion and mental arithmetic task, and resting levels) to verify the efficacy of the stress induction. We anticipated increases in heart rate, skin conductance levels, subjective stress, and subjective anxiety during both the instructions and stressor phases, as compared to the baseline. Conversely, we expected these measures to significantly decrease after the resting period for participants in the MAST group. In parallel, we predicted a reverse pattern in HRV for participants in the MAST group, with a decrease during anticipation and reactivity and an increase during the subsequent recovery period. Participants in the placebo-MAST group were not expected to show these three changes across the laboratory session. The potential influence of age and gender were considered in the analyses (e.g., Shapiro et al., 1996).

Hypotheses Testing by Axis

Given that we did not expect to see relationships with stress outcomes in the Placebo group, all following models were applied to the experimental group, only ($N \approx 85$). Preliminary to the multilevel models, we conducted correlations between all predictors, outcomes at all time points, sociodemographic variables (age, gender, years of education, handedness), and chronic stress. For the main multilevel models, all cognitive tasks were standardized. The R package *nlme* (Pinheiro et al., 2018) was used to compute all multilevel models. As recommended by Field and Wright (2011), model building was based on the lowest Akaike's Information Criterion (AIC). For each outcome, we computed a first model with random intercept effects, and a second with random effects on both intercept and slope. The latter always presented the lowest AIC; thus, we reported the results for these and model assumptions were also verified. Some outcomes were log-transformed to meet multilevel model assumptions for the reactivity model. For the recovery multilevel model, the comparison timepoint was set to the stressor phase, as such to capture recovery levels from the stressor to the resting phase.

Hypothesis 1: Executive Functioning and Stress Phases. We ran multilevel models for each stress outcome (STAI, heart rate, HRV, electrodermal activity, and blood pressure), with executive functioning facets, time (baseline, instructions, stressor, resting) and the interaction terms between executive functioning and time as predictors, along with relevant covariates (i.e., age, gender, education, chronic stress, and handedness) that correlated with the dependent and independent variables. We performed correlations between all independent variables to optimize model parsimony. For each stress outcome, participants with incomplete data were excluded from the respective model analyses.

Hypotheses 2, 3, and 4: Mediating roles of Cognitive Appraisals, Repetitive Negative Thinking, and Emotion Regulation. In an exploratory manner, we ran correlations (Pearson or Spearman depending on the normality of the distributions) between the executive functioning facets and all mediators. We ran three types of multiple mediation models using bootstrapping with Haye's PROCESS macro in SPSS Statistics (IBM Corp., 2017), with cognitive appraisals (primary and secondary appraisals measured at the instructions, T2), repetitive negative thinking (abstract-evaluative, concrete-experiential, and creative-dendritic modes at T2, and during the stressor, T3), and emotion regulation (reappraisal and suppression at T2 and T3). For parsimony reasons, we conducted these models when we observed a significant correlation between (a) an executive functioning facet and one potential mediator, and (b) the same mediator and a stress outcome. All correlations can be found in Supplementary Materials. In addition, we included baseline stress levels for all reactivity models, and the reactivity stress levels as covariates for the recovery models. This captured change from baseline to the instructions (i.e., anticipation), to the stressor (i.e., reactivity), and from the stressor to the resting period (i.e., recovery). We reported *p*-values and considered results as significant when they fulfilled the criterion of $p < .05$.

Sensitivity Analyses. We conducted additional sensitivity analyses by combining all four executive functioning scores into one composite measure. This approach allowed us to investigate whether the effects were replicated using one overarching executive functioning construct. These sensitivity analyses provided a more comprehensive perspective on the interplay between executive functioning and stress anticipation, reactivity, and recovery, assessing both the collective and distinct contributions of each facet to the observed outcome.

4.3. Results

Descriptive Statistics

A total of 267 participants were screened for the exclusion criteria, from which 114 individuals either did not meet the study criteria or could not be present at the physiology session. Three participants withdrew from the study due to the intensity of the stressor, while ten had erroneous or missing data on cognitive tasks. Two participants failed to respond appropriately to a specific attention check item embedded within the online questionnaires. Consequently, these fifteen participants were excluded from the analyses. The final sample is composed of 138 individuals, assigned randomly to the experimental ($N = 94$) and control ($N = 44$) group. The full sample description can be found in Table 5. There were no significant differences in age, gender, educational years, handedness, BMI, or chronic stress, indicating that the randomization process was correctly completed. Hence, we do not include these variables in the repeated-measures ANOVA.

Stress Induction Verification

Consistent with our hypotheses, the MAST generated a significant increase in all stress outcomes compared to the placebo-MAST (see Figures 3 and 4 and Table S1 in the Supplementary Materials). More specifically, we found a significant time × group interaction for systolic blood pressure [$F(2.43, 329.97) = 33.37$, $p <.001$, partial $\eta 2 = .20$], diastolic blood pressure [$F(2.40, 326.25) = 16.89$, $p <.001$, partial $\eta 2 = .11$], heart rate [$F(2.61, 343.97) = 33.40$, $p <.001$, partial $\eta 2 = .20$], RMSSD [$F(2.75, 366.18) = 7.90$, $p <.001$, partial $\eta 2 = .06$], skin conductance levels [$F(2.05, 274.96) = 11.02$, $p <.001$, partial $\eta 2 = .07$], self-reported stress [$F(2.74, 373.20) = 29.45$, $p <.001$, partial $\eta 2 = .18$], and self-reported anxiety levels [$F(1.58, 215.48) = 63.29$, $p <.001$, partial $\eta 2 = .32$].

Regarding systolic blood pressure, pairwise t-tests with Bonferroni corrections showed that compared to the control group, the experimental group presented significantly higher levels during the instructions ($p = .006$), stressor ($p < .001$), and resting ($p = .031$) periods (see Figure 13). During the stressor, participants in the experimental group exhibited significantly higher levels of diastolic blood pressure ($p<.001$), heart rate ($p = .016$), and skin conductance levels ($p = .008$), compared to those in the placebo-MAST group. For subjective stress, higher subjective stress levels were observed between groups during both the instruction ($p <.001$), and the stressor ($p <.001$; see Figure 14). For anxiety, participants in the experimental group reported significantly higher self-reported anxiety during the stressor ($p <.001$), and after the resting phase ($p=.043$), as compared to those in the control group. While multiple comparisons for RMSSD did not reveal significant differences between groups across phases, significant differences within the experimental group were observed across all phases except for the instructions and stressor phase.

Table 5. Descriptive Statistics according to Experimental Group

Variable	Experimental Group *N* = 94	Control Group *N* = 44	Group Differences
Sociodemographic Variables			
Age *M(SD)*	22.24 (4.14)	21.93 (3.65)	*F*(1,136) = 0.18, *p* = .668
Gender, *N(%)*			χ2(1, 138) = 0.66, *p* =.418
Women	58 (61.70)	31 (70.45)	
Men	36 (38.30)	13 (29.55)	
Years of Education, *M(SD)*	15.51 (2.28)	15.25 (2.04)	*F*(1,136) = 0.42, *p* = .519
Handedness, *N(%)*			χ2(2, 138) = 0.01, *p* =.997
Right-handed	81 (86.17)	38 (86.36)	
Left-handed	11 (11.7)	5 (11.36)	
Ambidexter	2 (2.13)	1 (2.27)	
Body Mass Index	23.45 (3.53)	22.60 (2.68)	*F*(1,136) = 2.03, *p* = .157
Chronic Stress, *M(SD)*	14.68 (6.37)	14.30 (6.90)	*F*(1,136) = 0.10, *p* = .748
Executive Functioning			
Flexibility	592.65 (289.93)	552.27 (289.33)	*F*(1,136) = 0.58, *p* = .447
Inhibition	187.01 (45.78)	183.90 (47.89)	*F* (1,136) = 0.13, *p* = .715
Updating	0.92 (0.13)	0.90 (0.09)	*F* (1,136) = 0.44, *p* = .510
WMC	48.07 (12.80)	44.23 (14.90)	*F* (1,136) = 2.44, *p* = .121

Note. WMC = Working Memory Capacity.

Axis 1: Executive Functioning and Stress Anticipation, Reactivity, and Recovery

The models revealed significant interactions between executive functioning facets and time, not only at baseline, but also for each phase of the MAST. First, both flexibility and updating were significantly associated with systolic blood pressure at baseline (see Table 6). Worse flexibility (higher scores) and better updating (higher scores) predicted higher systolic blood pressure at baseline, upon entering the laboratory. Higher scores of updating were also associated with higher anxiety scores at baseline. Second, in terms of anticipation, worse flexibility (i.e., bigger switch costs) was related to higher blood pressure and skin conductance levels after the instructions period, compared to baseline. Interestingly, worse inhibition (i.e., bigger stop-signal reaction times) was linked to greater systolic blood pressure and *lower* skin conductance levels following the stressor instructions. Third, in terms of reactivity, flexibility also interacted with the stressor phase for skin conductance, indicating that worse flexibility was associated with greater stress from baseline to the stressor (see Figure 15). Fourth, poorer flexibility (i.e., higher switch costs) predicted higher recovery scores after the resting period, as compared with baseline, for systolic blood pressure, mean skin conductance levels, and the stress item (see Table 7). This indicates that individuals with poorer flexibility presented higher stress levels despite having been given a resting period (i.e., *lower* return to baseline levels). Hence, flexibility had a significant impact on all three stressor stages when stress was measured using skin conductance levels (see Figure 15). Overall, individuals with higher flexibility benefited from lower baseline stress levels and showed lower skin conductance changes throughout each phase.

Sensitivity Analyses

A higher score of the general executive functioning factor was significantly associated with lower systolic blood pressure after the instructions, as compared to baseline (B = -2.98, SE = 1.07, p = .006). It was a nonsignificant predictor for all other stress phases and outcomes.

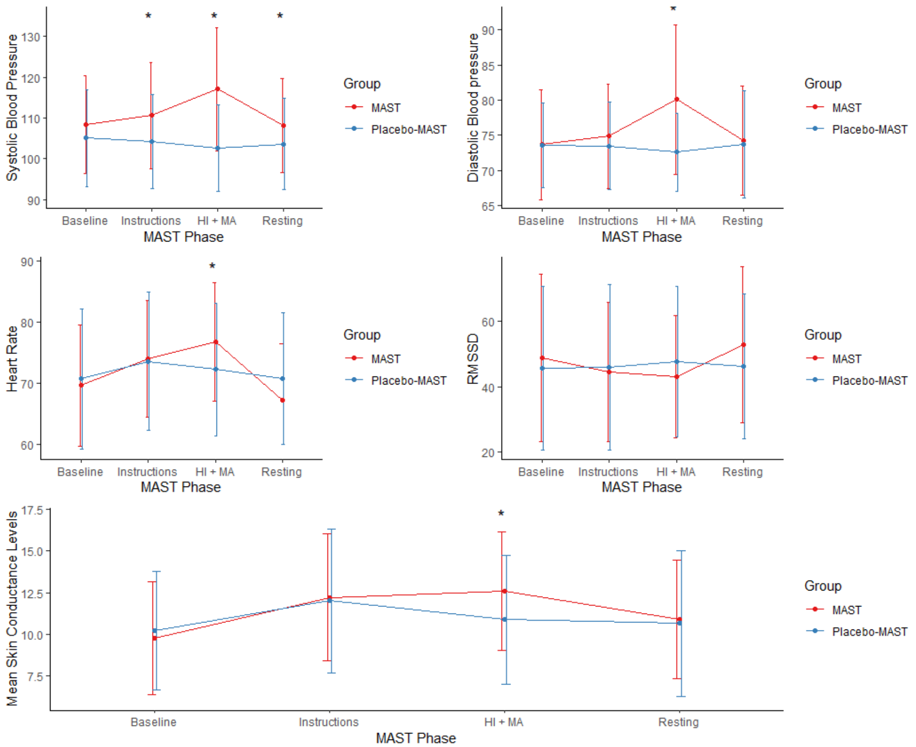

Figure 13. Stressor-Induced Changes in Systolic and Diastolic Blood Pressure, Heart Rate, RMMSD and Skin Conductance Levels according to Experimental Group

Note. *HI* = Hand Immersion; *MA* = Mental Arithmetic. * indicates significant differences between groups.

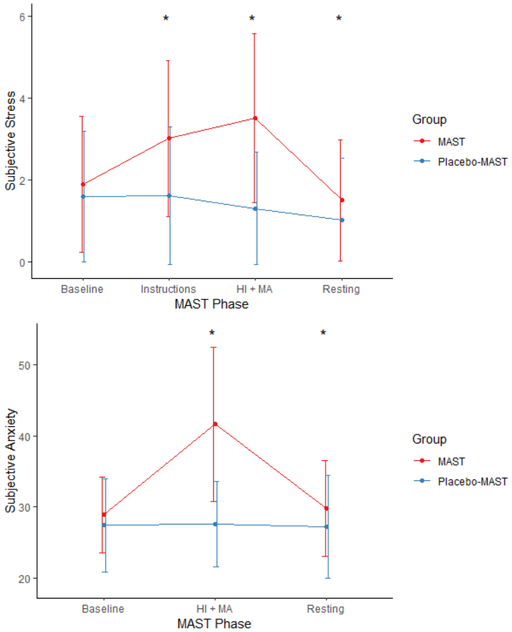

Figure 14. Stressor-Induced Changes in Subjective Stress and Anxiety according to Experimental Group

Note. *HI* = Hand Immersion; *MA* = Mental Arithmetic. * indicates significant differences between groups.

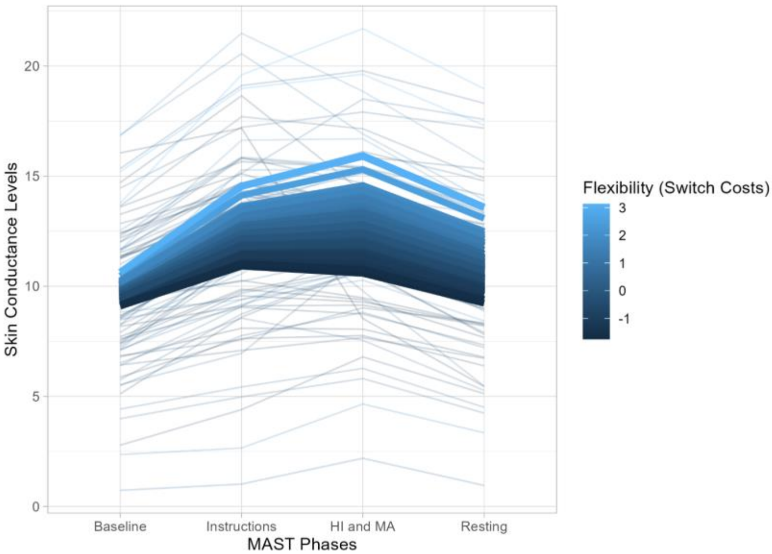

Figure 15. Interaction of Flexibility (Switch Costs) with all four MAST Phases to predict Mean Skin Conductance Levels

Note. Higher values (lighter blue) represent poorer flexibility capacity.

Table 6. Multilevel Regression Model: Change in Physiological Outcomes Throughout the Stressor

	SBP	DBP	HR	RMSSD[1]	SCL
Fixed Effects					
Intercept	**103.61*** (1.22)**	**73.67*** (0.81)**	**71.25*** (1.23)**	**1.65*** (0.02)**	**8.84*** (0.38)**
Time					
Anticipation	**2.21*** (0.54)**	**1.19** (0.43)**	**4.29*** (0.42)**	**-0.04** (0.01)**	**2.57*** (0.17)**
Reactivity	**8.67*** (0.94)**	**6.48*** (0.87)**	**7.12*** (0.66)**	**-0.04** (0.02)**	**2.85*** (0.24)**
Recovery	-0.21 (0.55)	0.57 (0.49)	**-2.37*** (0.35)**	**0.04** (0.01)**	**1.14*** (0.26)**
Flexibility	**-2.01* (0.98)**	-0.11 (0.82)	0.60 (1.01)	0.02 (0.02)	0.19 (0.31)[2]
Anticipation	**1.44** (0.54)**	-0.51 (0.43)	-0,04 (0,42)	0.01 (0.01)	**0.39* (0.17)[2]**
Reactivity	1.71 (0.94)	-0.86 (0.87)	0,01 (0,66)	0.003 (0.02)	**0.75** (0.24)**
Recovery	**1.58** (0.55)**	0.08 (0.49)	0.33 (0,35)	-0.01 (0.01)	**0.55* (0.27)**
Inhibition	-0.59 (0.98)	0.19 (0.83)	-1.73 (1.02)	0.02 (0.02)	-0.11 (0.31)
Anticipation	**1.52** (0.55)**	0.77 (0.432)	0,70 (0,42)	-0.01 (0.01)	**-0.53** (0.17)**
Reactivity	-1.60 (0.95)	-0.69 (0.88)	0,87 (0,67)	-0.01 (0.01)	-0.42 (0.24)
Recovery	-0.19 (0.55)	0.44 (0.50)	**0.85* (0,35)**	-0.02 (0.01)	-0.31 (0.27)
Updating	1.33 (1.04)	0.41 (0.87)	1.08 (1.08)	0.0003 (0.02)	-0.46 (0.33)
Anticipation	-0.80 (0.58)	0.48 (0.46)	-0.56 (0,44)	-0.003 (0.01)	0.08 (0.18)
Reactivity	-0.12 (1.01)	1.15 (0.93)	-0,92 (0,71)	0.01 (0.02)	0.16 (0.26)
Recovery	0.17 (0.59)	0.08 (0.53)	0,08 (0,37)	0.001 (0.01)	0.05 (0.28)
Working Memory	-1.14 (1.05)	-0.44 (0.88)	-1.38 (1.08)	-0.02 (0.02)	0.33 (0.33)
Anticipation	0.38 (0.58)	-0.54 (0.46)	0.45 (0,45)	-0.01 (0.01)	-0.14 (0.18)
Reactivity	-0.36 (1.01)	-1.55 (0.93)	0.28 (0,71)	-0.01 (0.02)	-0.28 (0.26)
Recovery	0.10 (0.59)	-0.55 (0.53)	-0.11 (0,37)	-0.001 (0.01)	-0.36 (0.28)
Age	--	**1.68* (0.74)**	--	--	--
Gender (Male)	**12.43*** (1.94)**	--	**-4.30* (1.93)**	--	**2.16*** (0.57)**
Chronic Stress	**-2.80** (0.94)**	--	1.57 (0.94)	--	--
Random Effects					
Intercept	9.01	7.53	9.37	0.20	2.88
SD (Anticipation)	3.64	2.53	2.94	0.08	1.23
SD (Reactivity)	8.27	7.74	5.70	0.12	2.09
SD (Recovery)	3.71	3.48	1.97	0.09	2.33
Residual *SD*	2.68	2.30	1.88	0.60	0.71
Number Obs,	376	376	364	368	372
Number Indiv.	94	94	91	92	93
AIC	2481.04	2375.59	2181.31	-325.46	1583.37
BIC	2608.73	2499.50	2307.86	-206.04	1706.92
ICC	0.758	0.612	0.724	0.767	0.683

Note. In these models, recovery is considered as the difference between stress levels during the resting period and the baseline. Therefore, higher values indicate poorer return to baseline. *AIC* = Akaike information criterion; *BIC* =Bayesian information criterion; *DBP* = Diastolic blood pressure; *HR* = Heart rate; *ICC* = Intraclass Correlation Coefficient; *Indiv* = Individuals; *Obs* = Observations; *SBP* = Systolic blood pressure; *SCL* = Skin conductance response; *SD* = standard deviation.

[1] Log-transformed;

[2] This variable becomes or stays significant in the recovery model.

Table 7. Multilevel Regression Model: Change in Psychological Outcomes Throughout the Stressor

	Stress[1]	Anxiety[1]
Fixed Effects		
Intercept	**0.39** (0.03)**	**1.47*** (0.01)**
Time		
Anticipation	**0.16*** (0.02)**	--
Reactivity	**0.21*** (0.02)**	**0.15*** (0.01)**
Recovery	**-0.06** (0.02)**	0.01 (0.01)
Flexibility	-0.04 (0.03)	0.0001 (0.01)
Anticipation	0.03 (0.02)	--
Reactivity	0.03 (0.02)	0.004 (0.01)
Recovery	**0.05* (0.02)**[2]	0.01 (0.01)
Inhibition	-0.02 (0.03)	-0.005 (0.01)
Anticipation	-0.003 (0.02)	--
Reactivity	0.01 (0.02)	-0.01 (0.01)
Recovery	0.02 (0.02)	-0.003 (0.01)
Updating	-0.01 (0.03)	**0.02*** (**0.01**)
Anticipation	0.002 (0.02)	--
Reactivity	0.03 (0.02)	-0.01 (0.01)
Recovery	0.04 (0.02)	-0.003 (0.01)
Working Memory	-0.001 (0.03)	-0.01 (0.01)
Anticipation	-0.01 (0.02)	--
Reactivity	-0.01 (0.02)	0.003 (0.01)
Recovery	-0.004 (0.02)	0.001 (0.01)
Age	--	--
Gender	--	-0.01 (0.01)
Chronic Stress	**0.10*** (0.02)**	**0.03*** (0.001)**
Random Effects		
Intercept	0.23	0.06
SD (Anticipation)	0.13	--
SD (Reactivity)	0.17	0.09
SD (Recovery)	0.18	0.06
Residual	0.08	0.03
Number Obs,	376	282
Number Indiv.	94	94
AIC	-83.61	-517.76
BIC	40.30	-431.85
ICC	0.509	0.167

Note. AIC = Akaike information criterion; *BIC* =Bayesian information criterion; *ICC* = Intraclass Correlation Coefficient; *Indiv* = Individuals; *Obs* = Observations; *SD* = Standard deviation.

Axis 2: Executive Functioning, Appraisals, and Stress

There were no significant associations between executive functioning and primary appraisals (Supplementary Table S2). Consequently, no mediational models were conducted. Higher primary (combination of threat and challenge) appraisals significantly correlated with higher self-reported anxiety and stress across all MAST phases following baseline (see Figure S1 in the Supplementary Materials).

Axis 3: Executive Functioning, Repetitive Negative Thinking Mode, and Stress

Abstract-Analytical Repetitive Thinking and Concrete-Experiential Repetitive Thinking

There were no significant correlations between any executive functions with either abstract-analytical or concrete-experiential mode (see Table S3), thus no further mediational models were conducted. However, it is worth mentioning that higher abstract-analytical thinking during the instructions phase (T2) was associated with higher self-reported stress during the instructions and stressor, as well has higher heart rate during the stressor and the resting period (see Figure S2 in the Supplementary Materials). Abstract-analytical thinking during the stressor (T3) was associated with higher anxiety and self-reported stress throughout the stressor and after the resting phase. The exact opposite pattern was found for concrete-experiential repetitive thinking during the stressor (T3), with it being associated with lower stress and anxiety throughout the phases.

Creative-Dendritic Repetitive Thinking

In additional exploratory analyses, better updating was associated with lower use of creative-dendritic thoughts during the instructions phase [$r(83) = -0.22$, $p = .044$], while better flexibility was associated with greater use of these thoughts during the stressor phase [$r(83) = -0.34$, $p = .001$)]. Creative-dendritic thoughts during instructions was associated with lower anxiety after the resting phase [$r(83) = -0.22$, $p = .047$], lower subjective stress at instructions [$r(83) = -0.32$, $p = .002$] and stressor [$r(83) = -0.30$, $p = .006$] phases. Similarly, creative-dendritic thoughts during reactivity were associated with lower subjective stress during the stressor [$r(83) = -0.24$, $p = .030$]. However, none of the mediation effects were significant (see Table S4).

Axis 4: Executive Functioning, Emotion Regulation, and Stress.

There were no significant associations between any of the four executive functioning facets and reappraisal or emotional suppression at any time point (see Table S5). Therefore, no further mediational models were conducted. Nonetheless, both higher use of reappraisal and suppression during the stressor were significantly correlated with higher anxiety and self-reported stress across most MAST stages (see Figure S3 in the Supplementary Materials). In addition, suppression use during the stressor was significantly correlated with higher systolic blood pressure levels during the resting period.

4.4. Discussion

The aim of this study was to determine the potential protective effect of flexibility, inhibition, updating, and working memory capacity on acute stress anticipation, reactivity, and recovery. The project was divided into four axes (see Figure 11), examining the association between executive functioning and (a) different phases of acute stress (Axis 1), (b) the formation of appraisals ahead of the MAST (Axis 2), (c) the presence of repetitive negative thinking in anticipation of and during the stressor (Axis 3), and (d) emotion regulation strategies implemented during both the instructions and the stressor (Axis 4).

Executive Functioning and Stress Responses

Stress Reactivity

Beginning with Axis 1, Hypothesis 1 predicted that better scores on all three facets of executive functioning (inhibition, flexibility, updating) and working memory capacity would be negatively associated with reactivity (i.e., lower stress reactivity), and positively with recovery indicators (i.e., faster return to baseline). This hypothesis was partially supported: flexibility was the only predictor of stress reactivity, irrespective of stress outcome considered. More specifically, better flexibility predicted lower reactivity for skin conductance levels. These results replicate findings by Hendrawan and colleagues (2012), who reported that better flexibility, as measured using a verbal fluency task, was linked to dampened levels of state anxiety, negative mood, salivary cortisol, and skin conductance in response to the TSST. Similarly, in a study measuring flexibility, inhibition, and updating ahead of an acute stressor, Guevara and Murdock (2020) had also found only flexibility to be associated with lower cortisol output during an acute stressor (i.e., using area under the curve). Therefore, our results suggest that when accounting for all cognitive functions and all stages of an acute stress induction, cognitive flexibility is the most relevant facet for promoting more adaptive physiological stress responses.

Contrary to the registered hypotheses, neither inhibition, updating, nor working memory capacity were significantly related to stress reactivity. This finding was unexpected, given that a previous meta-analysis, pooling data from seven studies, established a significant association between higher working memory capacity and reduced cortisol reactivity to acute stress (Grimm et al., 2021). The qualitative systematic review conducted by these authors described separate studies investigating other stress-related outcomes. The latter had not reported significant associations for working memory capacity with other stress outcomes, such as with alpha-amylase and subjective stress. Similarly, significant findings for updating in the same review were limited to cortisol. Finally, the same absence of an association between inhibition and stress reactivity was reported in a systematic review (Grimm et al., 2021), with respect to cortisol, alpha-amylase, blood pressure, heart rate, HRV, skin conductance levels, and subjective stress. Hence, the current study did not allow for the verification of a relationship between any of these three facets and stress reactivity. Flexibility emerged as the most relevant candidate for preventing excessive stress reactivity, specific to skin conductance levels.

Stress Recovery

In partial alignment with Hypothesis 1, better flexibility was also associated with faster recovery time (*i.e.*, better recovery: smaller difference between baseline and resting levels) for systolic blood pressure, skin conductance levels, and self-reported stress. Additionally, better inhibition was associated with a prompter recovery to baseline heart rate levels. This indicates that better both flexibility and inhibition may be involved in promoting a faster recovery after acute stress and, thus, in enabling homeostasis.

Regarding the lack of findings for updating and working memory capacity, it is worth noting that across the 10 studies investigating executive functioning and post-stressor recovery in Grimm et al. (2021)'s review, only four found significant associations with executive functioning, none of which concerned updating and working memory capacity. Therefore, the current results replicate previous conclusions and extend them to other stress outcomes: updating and working memory capacity appear unrelated to acute stress reactivity and recovery.

Stress Anticipation

Beyond these findings for reactivity and recovery, exploratory investigations for anticipation also revealed significant effects for flexibility and inhibition, in partial alignment with Hypothesis 1. Better flexibility predicted lower anticipatory systolic blood pressure and skin conductance levels (i.e., lower change from baseline to the instructions phase). In the experimental group, it is interesting to remember that significant changes were observed for systolic blood pressure, heart rate, RMSSD, skin conductance, and self-reported stress during the instructions, as compared to baseline. For RMSSD and skin conductance, there were no significant differences in stress averages during the instructions phase and the stressor itself, indicating a robust activation of the body's stress response system in anticipation of the challenging situation, but no further stressor-related increases. Therefore, cognitive flexibility may also act as a buffer, preventing sustained blood pressure responses across to the other phases.

Likewise, better inhibition predicted lower anticipatory systolic blood pressure changes but, surprisingly, higher changes in skin conductance levels. Shifts in biological markers in anticipation of a stressor are seen as adaptive, flexible physiological responses (Madison, 2021), notably as they enable individuals to implement behavioral, cognitive, and physiological adjustments to deal with the upcoming event (Neupert et al., 2016; Schlatter et al., 2021). Under stress, to body releases a series of hormones that trigger increases in blood pressure and heart rate. Sustained activation of these systems, however, is a risk factor for worsening mental and physical health trajectories, including the risk of mortality (Madison, 2021). Thus, a flexible physiological response includes the limited activation of such reactions.

In contrast, the anticipation of an upcoming stressful situation also generates a skin conductance response, resulting from autonomic activation of the sweat glands (Christopoulos et al., 2019). This unconscious response to threat-related physiological signals the brain for mobilization for action if needed (Bradley et al., 2001; Hildebrandt et al., 2016). Thus, somatic responses such as skin conductance are fundamental to (a) prepare the brain for a response in anticipation of the upcoming event, and (b) to allow for an adapted appraisal of the situation (Christopoulos et al., 2019). This response can either occur before the conscious experience of emotion arises, serving as its precursor, or can also manifest itself as the emotion response itself. Delayed skin conductance responses to an anticipated stressor are typical indices of anxiety disorders, where autonomic responses are inhibited or regulated (Olatunji et al., 2007).

Given the literature in this field, our findings could be interpreted in two ways. On the one hand, the skin conductance captured in this study may have served as an index of anticipatory behavioral responses to the instructions. If this was the case, better inhibition was related to a greater behavioral response to face the upcoming stressor task, which would be considered adaptive. On the other hand, the skin conductance could have, instead, represented a proxy for the emotional response ahead of the anticipated, upcoming stressor. In this case, better inhibition would be considered counterproductive for the emotional experience. Greater inhibition of emotional information and cues during the MAST instructions may have led to sustained signals by the body encouraging further anticipatory action. This could be related to the avoidance of emotions induced by the instructions. Our design does not allow us to conclude between these two explanations, thus future fundamental research should focus on understanding the influence of inhibition on anticipatory skin conductance responses in the context of acute stress.

Executive Functioning and Cognitive and Behavioral Mechanisms

Executive Functioning and Cognitive Appraisals

Beyond the main effects of executive functioning on stress (Axis 1), the current study also examined whether this relationship was mediated by cognitive appraisals (Axis 2), repetitive negative thinking (Axis 3), and emotion regulation strategies (Axis 4). To begin with appraisals, we expected better inhibition and working memory to be associated with more adaptive appraisals (higher challenge and lower control; Axis 2, Hypothesis 2a). In turn, we anticipated a decrease in physiological and subjective activations during the reactivity phase, and a quicker return to baseline levels during the recovery phase

(Hypothesis 2b). Our study failed to find evidence supporting our hypotheses, as no significant correlations emerged between executive functioning and primary appraisals. Furthermore, the secondary appraisals subscale exhibited notably poor reliability, which prevented us from further interpreting results relating to it.

Given the poor reliability of the challenge subscale, we resorted to using the primary appraisal sum score, combining both challenge and threat. Contrary to previous work (Panganiban & Matthews, 2014; Zandara et al., 2016) we found no evidence for associations between executive functioning and primary appraisals. It may be that executive functioning is not involved in the forming of appraisals regarding a stressful event. For example, Slattery and colleagues (2013) arrived at a similar conclusion in a sample of adolescents. Appraisals are automatic processes formed when one's resources are thought to be overwhelmed by the demands of the event (Lazarus & Folkman, 1984b). Given the automatic nature of these appraisals, it is likely that executive functioning may rather be exerted when individuals attempt to deal with the stressor.

Alternatively, the absence of the effect may also be due to the conceptualization of the PASA (Gaab et al., 2005). Looking closely at the items, one can see that the "threat" subscale included items relating to finding the stressor "threatening" and "unpleasant", as well as the situation "generating worries" and "instigating fear in the participant". One may thus question the extent to which such an appraisal measure overlaps with connected concepts, such as stress and worry. Examining the theoretical differences between these, therefore, requires further conceptual work. Similarly, "challenge" was composed of items relating to the situation "being important", the situation "being a source of worry", and two items relating to the extent to which the situation represents a challenge. One may notice an overlap with the worry-related items included in the threat subscale. Moreover, challenge was initially defined as the belief that one has the personal resources to deal with the current situation, recognizing one's own propensity for growth or gain (Peacock & Wong, 1990). As discussed elsewhere (Grimm et al., 2024), future studies interested in measuring appraisals in the context of acute stress should work on incorporating items tapping into how the stressor represents such an opportunity for growth and reduce its overlap with threat. On the whole, the evidence for a mediating effect of appraisals was inexistant.

Executive Functioning and Repetitive Negative Thinking

Regarding Axis 3, we found no evidence for a significant mediating role of repetitive negative thinking linking executive functioning facets with stress anticipation, reactivity, or recovery. More specifically, we found no significant associations between executive functioning and either concrete-experiential thoughts or abstract-analytical repetitive thoughts throughout the stressor (Hypothesis 3a). These results were unexpected, given the numerous research establishing that deficits in executive functioning were associated with higher reports of rumination (Cropley et al., 2016; Joormann et al., 2011; Watkins & Roberts, 2020; Whitmer & Banich, 2007; Yang et al., 2017). Our results indicate that when taking a more fine-grained approach to rumination and investigating modes of processing, a lack of relationship emerges. It is worth considering that the absence of results may be, in part, due to measurement errors. The internal consistency was acceptable for abstract thoughts during the instructions phase but not during the MAST, while the concrete subscale presented very poor internal consistency during both phases. While the questionnaire may be adapted for experimental inductions of repetitive thought (Philippot, 2019), it requires further work for adaptation in the context of acute stress induction.

However, the correlations do provide evidence linking the repetitive negative thinking modes to the Perseveration Cognition Hypothesis (Brosschot et al., 2006). Abstract-repetitive thinking and concrete-experiential thought presented opposite associations with stress responses. As expected, the former was positively correlated with prolonged stress responses, for stress, anxiety, and heart rate. The latter was related to lower patterns of self-reported stress and anxiety across all stages of the MAST. Therefore, investigating different modes of repetitive negative thinking provides further nuances to the existing framework, identifying that the concrete mode of thinking under stress may be particularly beneficial in limiting excessive stress responses.

In an exploratory manner, however, we did find evidence for significant associations between executive functioning and a third mode of repetitive thinking: creative-dendritic thoughts. It is important to note that creative thinking was more normally distributed during the instructions phase, while it was slightly skewed to the left during the stressor. This aligns with previous work finding that acute stress impairs creative thinking (Wang et al., 2019), thereby indicating a lower usage of it when under stress.

We had hypothesized that inhibition and flexibility would be the most relevant facets for repetitive negative thinking (Ottaviani, 2018; Watkins & Roberts, 2020). Flexibility and updating emerged as significant predictors of this specific mode. Better updating measured at baseline was associated with *lower* creative thinking during the instructions. Therefore, individuals with a higher capacity for continuously updating material in working memory were less likely to resort to creative thinking in response to the instructions. This finding is surprising, as previous research investigating creative thinking had linked better working memory (Lin et al., 2018) and updating (Zhao et al., 2023) in adolescents with better creativity. Moreover, updating training has shown significant improvements in creativity (fluency and flexibility, specifically; Zhao et al., 2023). Perhaps this effect may be specific to the creativity tasks implemented, often measuring convergent and divergent thinking (e.g., the Remote Association Test; Mednick, 1962, or the Unusual Uses Test; Silvia et al., 2008). These concepts relate to seeking one or multiple solutions often to a precise administered task. The concrete thinking measure implemented in this study, however, represented a broader measure of creative thoughts in response to an acute stress. Thus, previous measures and designs were very different to the current study; it is likely that updating may not be activated to the same extent in both contexts. Alternatively, it also may be that individuals with better updating in the current study did not need to rely on updating during the stressor. Other cognitive processes may have been involved.

In contrast, better flexibility was associated with greater creative thinking implementation during the stressor. This significant finding replicates results from a systematic review in children and adolescents (Pasarín-Lavín et al., 2023). Their results indicated a clear positive association between flexibility and creativity, as well as a negative correlation between inhibition and creativity. They found no evidence for other executive functions. Therefore, individuals with better flexibility (as measured with set-shifting) may be more creative in their thinking when enduring stress. This effect might also be specific to the stressor phase, as the correlation did not emerge for the anticipatory phase. Interestingly, Redifer et al. (2019) have previously reported that the association between working memory and creative thinking was fully mediated by cognitive load. It may be that the cognitive load imposed by the arithmetic task part of the MAST led to reduced creative thinking during this phase, as noted by the lower variability in distribution of this variable during the stressor. If this was the case, the importance of cognitive flexibility is even greater: it represents an important resource against stress-induced deficits in creative thoughts.

Despite these interesting results, Hypothesis 3b could not be verified for two reasons. First, the mediation models were conducted only for significant correlations to prevent data dredging. The absence of significant associations between executive functioning and abstract and concrete thinking prevented further mediation model implementation. Second, none of the exploratory mediation models found evidence for a significant mediating effect of creative thinking. The effect of flexibility and updating on stress responses were not significantly mediated by creative thinking. Therefore, we cannot conclude that creative thinking – or other repetitive thoughts – are implicated in this relationship.

Executive Functioning and Emotion Regulation

Finally, Axis 4 explored the role of emotion regulation strategies implemented during an acute stressor. Inhibition, flexibility, and updating were expected to be associated with higher reappraisal and lower suppression (Hypothesis 4a). In turn, we expected that these should promote lower stress reactivity and faster recovery (Hypothesis 4b). This hypothesis was not supported by the results. None of the executive functioning facets correlated significantly with reappraisal or suppression implemented, both during the instructions and the stressor induction.

Given the recent frameworks and evidence linking executive functioning and emotion regulation (Crum et al., 2020; Hendricks & Buchanan, 2016; Johnson, 2009; Pruessner et al., 2020; Schmeichel & Tang, 2015; Zelazo & Cunningham, 2007), these null findings were surprising. The adapted ERQ showed good reliability for all four outcomes, suggesting that measurement issues could be ruled out. It is important to note, however, that reports for both strategies were skewed to the right during the instructions phase, with only slightly more variability during the stressor. Given the intensity of the stressor, one may question the extent to which participants either (a) implemented these strategies during the instructions and stressors, and (b) were aware of their own regulating efforts during both phases. In both cases, it is possible that participants underreported their emotion regulation strategies.

Alternatively, the ERQ was limited to the measurement of two strategies. Perhaps individuals implemented other emotion regulation or coping strategies during the stressor that were not accounted for by our design. Moreover, beyond the evaluation of strategy choice, we did not capture strategy stopping and switching, which may more likely be associated with facets like inhibition and flexibility (Pruessner et al., 2020). Designs focused on the flexibility in emotion regulation choice may be more relevant for revealing the role for executive functioning. Additionally, both strategies were focused on individuals' relations to both positive and negative emotions. Schmeichel and Tang (2015) argued that inhibition would be useful for suppressing negative emotions to stressful events, while updating would be more useful for modifying emotional appraisals within working memory. As both positive and negative emotions were combined, we were unable to decompose this effect, which may also explain the null findings. Therefore, while the results do not align with previous research, they did provide reliable information regarding the use of emotion regulation during different stages of an acute stressor. Replicating this design with measures capturing other strategies [e.g., using the Cognitive Emotion Regulation Questionnaire (Garnefski & Kraaij, 2007) or the Behavioral Emotion Regulation Questionnaire (Kraaij & Garnefski, 2019)] and adapting them for their use during acute stressors may further develop our understanding of executive functioning and emotion regulation during stress.

A Case for a More Granular Approach to Executive Functioning

Another important contribution stemming from our results is the use of a fine-grained approach to executive functioning in the domain of stress. When considering a general standardized factor to measure executive functioning, the only remaining significant effect appeared with anticipatory systolic blood pressure, where better executive functioning predicted lower increases during the instructions phase, as compared to the baseline. This is important as this signals the relevance of specific facets in playing differing roles across different phases of acute stress. The ongoing debate regarding a universal definition and measurement of executive functioning is well known (Baggetta & Alexander, 2016). Our results prompt for investigations regarding the independent contributions of each facet. Equally important, it is plausible that previous research that has evaluated executive functioning as a general score may have missed out on more nuanced effects. Thus, future research should administer diverse executive functioning tasks and consider their respective impact on stress responses.

Flexibility and Inhibition: Implications for Acute Stress and Future Research

Altogether, our results found that flexibility and inhibition were correlated with more adaptive stress responses. These results align with the Stress Optimization Model (Crum et al. 2020), which integrates theories on stress mindsets and reappraisal. Within the framework, attentional deployment is identified as a key mechanism for optimizing stress responses, that is, to lean into – rather than avoid – stressful situations to reach valued goals. Shifting the attentional focus away from the negative aspects of stress, towards information relating to opportunities and goals associated with the stressor can allow the individuals to engage with stress. Fundamentally, this requires both inhibition (e.g., inhibiting negative information) and flexibility (shifting one's attention to goal-related aspects of the stressful situation). This provides important implications for the potential of training inhibition and flexibility during acute stressors. For example, a training paradigm has been devised, instructing individuals to focus their attention on positive or negative stimuli based on the contextual goal activated (Godara et al., 2021). Adapting this paradigm to stressful situations could offer promising insights for stress regulation.

The findings also provide new understandings on flexibility. Flexibility in stress responses refers to the ability to mobilize physiological resources in a manner that is proportional to the perceived threat (Madison, 2021). Accordingly, flexibility in physiological stress responses implies (a) a certain degree of physiological activation when facing a stressor and (b) a return to baseline when the threat is no longer present are adaptive for the organism. In the context of stress regulation, such flexibility is narrowly related to (a) autonomic flexibility (i.e., higher resting heart rate allows individuals to adapt and respond appropriately to environmental stimuli), (b) psychological flexibility (i.e., disengaging from actions that are not aligned with a person's goals or values, and implementing alternative options; Kashdan, 2010), and emotion regulation flexibility (i.e., variations in the use of strategies in synchronization with changes in the environment; Aldao et al., 2015). Our results attempt to bridge these concepts together, gathering evidence for the implication of cognitive flexibility – as measured using a neuropsychological task – during acute stress. Often, these concepts are studied by separate research fields that seldom work to integrate other approaches. Thus, it is imperative for future work to combine these different frameworks, as such to provide a complete definition of flexibility and to study its relationship with stress, resilience, and mental health.

The strength of this study nonetheless lies in its comprehensive approach, which incorporated a diversity of cognitive tasks and stress measures within a single paradigm. By including a control group, we were able to assess the effectiveness of the induction and ensured the reliability of the stress responses observed. Moreover, our method enabled a thorough operationalization of distinct stress responses—anticipation, reactivity, and recovery— and provided a holistic view of acute stress dynamics. Finally, we examined potential mechanisms—such as appraisal, repetitive negative thinking, and emotion regulation — potentially linking executive functioning and stress. In striving to understand their implication, our study found only direct effects between executive functioning and stress.

Limitations

Despite the novelty of these findings, several limitations must be reported regarding the study methodology. First, it is worth noting that although there were significant differences between experimental groups across all measures of psychological and physiological stress, the average stressor-related increase in the MAST group remains relatively low. Thus, one may question the extent to which a more consequential stressor may allow for a stronger effect of the executive functioning facets. Nonetheless, Dickerson and Kemeny (2004) listed social-evaluative threat, novelty, uncontrollability, and motivated performance as key ingredients for laboratory stressors to elicit strong cortisol responses, all of which are characteristics of the MAST (Shilton et al., 2017; Smeets et al., 2012). Future studies could thus attempt replicating these effects using different stressors (Ernst et al., 2023; Skoluda et al., 2015; von Dawans et al., 2021). Similarly, the absence of cortisol measures – the main hormone of stress – also brings a constraint to the generalizability of the results. In a previous meta-analysis, an effect between working memory capacity and cortisol reactivity had specifically been confirmed (Grimm et al., 2021). However, cortisol being a more delayed response to stressors, a longer anticipatory phase is required to observe such activity during anticipation (Engert et al., 2013). Thus, the use of alternative measures of stress allowed us to capture real-time changes within a five minute-window of anticipation, nonetheless.

Second, it is important to acknowledge the low reliability of questionnaire measures applied during the MAST, particularly regarding appraisal and repetitive thinking. The strength of this study was to capture not only *state* repetitive thinking, but also specific *modes*, seldom studied in this context of acute stress. Although the aim was not to validate these measures in the French language, it was unexpected to find such low internal consistencies. We would recommend further work on the development and validation of these measures, in the French language, and in the laboratory.

Third, a main limitation of the design is its correlational nature. To establish causality, studies should incorporate the separate manipulation of each executive functioning facet, followed by the administration of the acute stressor. Individual changes in these facets and how they associate with subsequent stress responses would shed light on the causality of this relationship. Additionally, as this study focused on executive functioning tested at baseline, we cannot conclude that the same processes are observed when individuals use their executive functions under stress. In fact, stress-induced cognitive deficits have been observed for specific facets of executive functioning (Shields et al., 2016). Future studies could consequently investigate the associations with acute stress when comparing executive functioning at baseline and under stress.

4.5. Conclusion

To conclude, our results provide evidence for cognitive flexibility and inhibition being associated with more adaptive and flexible stress responses to acute stress. Overall, better scores on both facets were related to more adaptive stress responses in anticipation of the stressor (*i.e.*, during the instructions phase) and better recovery (i.e., lower levels of stress after the resting period). Flexibility was further associated with lower stress reactivity. However, there was no evidence for significant mediating effects of appraisals, repetitive negative thinking, or emotion regulation. Thus, the results suggest promising avenues for future research on the roles of flexibility and inhibition in stress regulation. Integrating neuroscience and stress research is now warranted for a thorough understanding of the neurological, physiological, and psychological interactions at play in this association.

Chapter 5.

Executive Functioning as a Predictor of Daily Stress Reactivity and Recovery: An Ecological Momentary Assessment Study

The exposure, reactivity, and recovery to daily stress have important ramifications for mental and physical health. The aim of this study was to establish the role of cognitive flexibility, inhibition, updating, and working memory capacity for reactivity and recovery to stressful events occurring on a daily basis. A total of 120 participants completed four computerized cognitive tasks in the laboratory. Over the next seven days of EMA data collection, participants received six notifications a day on the m-Path smartphone application, scheduled in 2-hour intervals from 9:00 AM to 9:00 PM. Participants also had the opportunity to spontaneously report stressors outside of the planned notifications. At each beep, they responded to items regarding their current mood and specified whether they had encountered a stressor since the last notification. Participants also reported the type of stressor and level of stress, as well as perceptions of threat/challenge, control over the stressor, and implemented affect regulation strategies. Using linear mixed models, the results showed that higher working memory capacity predicted lower stress levels when a stressor was reported. Contrary to expectations, none of the executive functioning facets significant predicted proximal or cumulative stress reactivity and recovery in the regression models. Furthermore, none of the appraisals or the affect regulation strategies mediated the association between executive functioning and stress responses. Finally, poorer cognitive flexibility was significantly correlated with higher within-variability in adaptive affect regulation strategies and with higher between-variability in maladaptive strategies. In multiple regression models, poorer inhibition significantly predicted greater between-variability in adaptive strategies. We discuss the implications for executive functioning in stress responses and affect regulation flexibility when confronted with daily stressors.

Reference

Grimm, E., Blanchard, A., Neupert, S.D., Scalbert, M. & Agrigoroaei, S. (2024). *Executive Functioning as a Predictor of Daily Stress Reactivity and Recovery: An Ecological Momentary Assessment Study*. Internal UCLouvain report: unpublished.

5.1. Introduction

Daily stressors refer to the routine challenges of everyday life (Almeida, 2005). They include both predictable (e.g., caring for a child or commuting to work) and unpredictable events (e.g., work deadlines or unexpected traffic; Piazza et al., 2013). Although often minor, their accumulation across time and across different domains can be detrimental for one's mental and physical health (Haight et al., 2023). Days characterized by the occurrence of daily stressors are associated with higher presence of physical health symptoms and exacerbation of existing health conditions compared to stressor-free days (Almeida et al., 2011). Daily stressors also appear to elicit changes in biomarkers of the cardiovascular, immune, and neuroendocrine systems (Piazza et al., 2010). Current research on acute stress is frequently conducted in controlled, laboratory settings. However, stressful events tend to be dynamic over time, making it crucial to account for within-person variability in response to ecological stressors, rather than limiting observations to a very specific stress induction (Sliwinski et al., 2009; Smyth et al., 2023).

Ambulatory assessment methods, such as ecological momentary assessments (EMA), offer more effective designs for studying stress in natural settings. EMA involves participants receiving multiple daily notifications over several days. They are prompted to complete self-reports of their momentary experiences, including affect, behaviors and context (Shiffman et al., 2008). This method reduces biases common in laboratory settings, or other experimental settings, and allows for the analysis of the temporal and dynamic features of the stress experience (Trull & Ebner-Priemer, 2013). Its benefits include minimizing potential mnemonic biases and capturing intra-individual variation and changes in variables (Shiffman et al., 2008). This design enhances the ecological validity of the findings by enabling the investigation of stressful event incidence, stress reactivity, and recovery in real-life settings.

Stress Reactivity and Recovery

EMA designs offer several approaches to capturing stressor-related events. For example, researchers can focus on exposure to actual stressors, asking participants to report the occurrence of stressful events (through a yes or no answer) or the number of stressful events throughout the day (for a review, see Weber et al., 2022). Stressors are often defined as unpleasant events having occurred "since the last beep" or "at that moment" (e.g., Zawadzki et al., 2019). To capture the severity of participants' stress when these events take place, researchers will invite participants to complete a visual analog scale to capture the magnitude of the stress (e.g., "how stressed are/were you?"; Weber et al., 2022) or negative mood experienced either at the current moment or at the moment of the stressor (e.g., Smyth et al., 2018).

In the last decade, researchers have increasingly recommended more precise measures of stress reactivity and recovery in daily settings. *Reactivity* to daily stressors is the "changes in affect, cognition, or physiology in response to daily stressors" (Ong & Leger, 2022). Researchers have defined a proximal and cumulative index of daily stress reactivity. *Proximal* reactivity is calculated by subtracting the level of stress or negative mood at the last reported beep where no stressor occurred t_{-1}, from the level of the current stressor moment (*t*; see Figure 16A; Smyth et al., 2023; Vaessen et al., 2017). *Cumulative* reactivity are responses to stressors that are calculated with respect to a person's "resting state." To calculate this resting state, one must aggregate stress or negative mood across all available non-stressor moments that occurred prior to the stressor (Figure 16B). More information regarding these calculations will be provided in the method section.

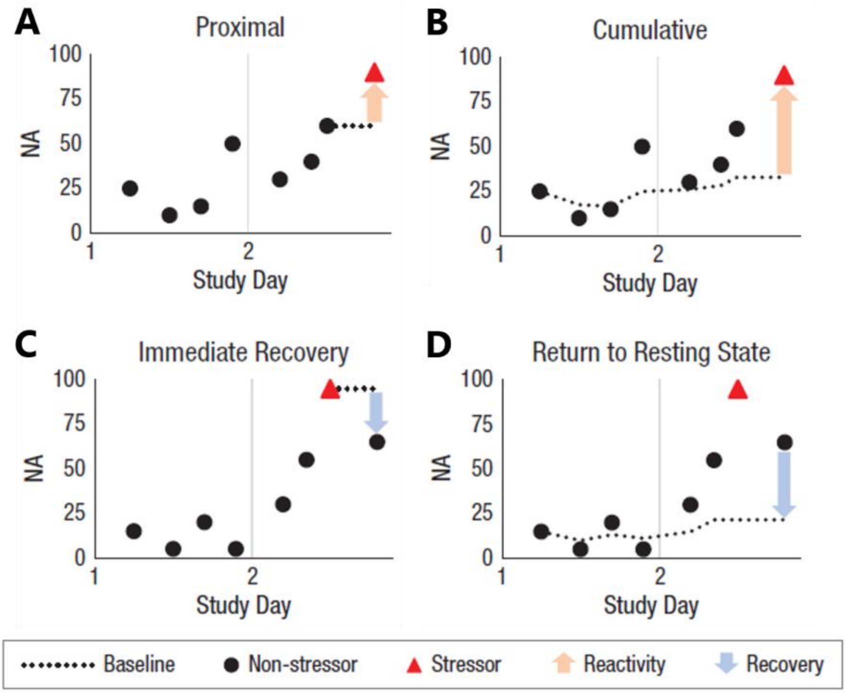

Figure 16. Proximal and Cumulative Stress Reactivity and Recovery

Note. Figure copied and adapted from Smyth and colleagues (2023) with permission of Elsevier.

Recovery, meanwhile, can be conceptualized as the reduction of "activation levels in affect, cognition, and physiology following a stressor" (Ong & Leger, 2022). When studying daily stress, proximal, or immediate, recovery reflects the changes from a peak during a stressor moment to a subsequent non-stressor period (see Figure 16C; Smyth et al., 2023). Cumulative recovery, or the return to one's resting state, will be calculated with respect to the person's resting state, capturing change from this peak of stress to a previously ongoing situation or context (i.e., Figure 16D). Prolonged stress reactivity and delayed recovery have important consequences for both mental and physical health

(Geurts & Sonnentag, 2006). These responses are also influenced by other cognitive and behavioral stress processes, including stress appraisals and affect regulation.

Stress Appraisals

Stressor appraisals play an important role in how one will experience exposure to daily stressors. Lazarus and Folkman (1984) defined the construct as a two-step parallel process. Primary appraisal involves determining whether a stimulus is threatening or benign and assessing its significance to one's well-being. Secondary appraisal entails evaluating the personal and situational resources available to manage the stressor, such as its controllability. The model emphasizes the interplay between primary and secondary appraisals in determining the overall impact of the stressor on well- being and whether the individual has sufficient resources to cope with it (Tsai et al., 2019).

Adaptation of appraisal measures for daily life have allowed for replication work on the effects of appraisals on daily stressors. For example, in a study on daily hassles and cortisol responses, higher appraisals of stress (i.e., where perceived demands exceeded resources) were associated with a lower increase in the cortisol awakening response the following morning (Gartland et al., 2014). Thus, accounting for the way individuals appraise negative events will also provide important information on stress responses.

Affect Regulation: Investigating Variability and Flexibility in Daily Life

A key factor for promoting optimal stress responses is the implementation of affect regulation processes (Arnold et al., 2023). The latter refer to the emotion regulation and coping strategies that individuals implement when faced with stressful events. Regulating and processing an emotion and/or feelings of stress first involves focusing one's attention on the emotion, appraising the emotion and its meaning in relation to one's goals, and providing a response to the emotion (e.g., upregulating or downregulating it; Gross, 1998). Traditionally, affect regulation strategies have been characterized as either "adaptive" or "maladaptive" (Aldao et al., 2010). For example, in studies on emotion regulation, reappraising emotions or directing one's efforts towards the stressor or its associated emotion is often found to have more positive emotional consequences (such as the reduction of negative affect and greater problem solving), while the opposite has been traditionally reported for suppression (Gross & John, 2003).

Similarly, coping strategies were considered adaptive if they sought to narrow the perceived gap between perceived stress and resources (Skinner et al., 2003). Adaptive coping encompassed implementing actions, planning, and seeking resources or support to address the problem. In contrast, maladaptive strategies enable the seeking of immediate emotional relief without tackling the stressor's root cause, widening the gap between situational demands and resources and heightening perceived stress (Lazarus & Folkman, 1984b). Strategies focusing on avoidance rather than problem-solving, such as denial or disengagement, were typically considered maladaptive due to their short-term reduction in distress without actually addressing underlying issues (Bardeen, 2015). This was also replicated in EMA designs, with a systematic review reporting that reappraisal and distraction were prospectively associated with positive affect at the next beep, while rumination and suppression were related to both ongoing and next-beep negative affect (Boemo et al., 2022). Rather than categorizing strategies as adaptive versus maladaptive, accounting for how and when these strategies are implemented may also play an important role in understanding stress responses.

Recent approaches to affect regulation integrate the importance of flexibility when implementing strategies to regulate emotions (Aldao et al., 2015). Different assessments for evaluating the dynamic of affect regulation, emotions, and stress have been suggested (for a review, see English & Eldesouky, 2020). For example, the "repertoire of strategies, the variability of strategy use across time and contexts, and the ability to use a diverse range of strategies" have all been proposed as indices of emotion regulation flexibility (Bonanno & Burton, 2013; English & Eldesouky, 2020). EMA allows for the measurement of how much individuals endorse specific strategies when facing a stressor (i.e., the extent to which they use an individual strategy to handle each new stressor). Notably, it introduces new methods to measure two important indices not yet assessed outside EMA designs: strategy variability and flexibility.

On the one hand, variability in affect regulation refers to the fluctuation in the use of one or more strategies across different situations and contexts (Aldao et al., 2015; Blanke et al., 2020; Elkjær et al., 2022). Variability can be examined both at the level of one singular strategy, as well as across multiple strategies in this research. A distinction can be made between *within* and *between* variability. *Within* variability refers to fluctuations in the intensity of a single strategy's usage across different stressors (e.g., always resorting to rumination every time one is confronted with a stressful event is representative of low within variability for that strategy). Higher within-variability scores indicate using a strategy more frequently for certain stressors and less for others. *Between* variability, meanwhile, represents the variability in selecting a strategy from a pool of strategies for each independent stressor (e.g., when exposed to a stressful event, high endorsement of all possible assessed strategies represents low between-variability; Blanke et al., 2020). Higher between-variability scores indicate varying levels of engagement with different strategies, meaning some strategies are favored more than others to face a specific stressor. Blanke and colleagues (2020) found that higher between-variability scores were linked to lower levels of negative affect in daily life. Southward and Cheavens (2020) also reported that higher between-variability in adaptive strategies (adaptive engagement, enhancement, and behavioral strategies) and lower between-variability in maladaptive strategies (expressive suppression, rumination) predicted lower mood.

On the other hand, flexibility in affect regulation refers to the ability to use different strategies *independently* across varying contexts (Aldao et al., 2015). This independence differs from variability in affect regulation, where an individual may frequently change their strategy use (high variability) but consistently rely on the same strategies to the same degree (low flexibility; Elkjær et al., 2022). Aldao et al. (2015) further highlight that flexibility in affect regulation is adaptive if it is embedded in a situational context. Thus, flexibility in emotion regulation emerges when individuals (a) appraise contextual demands, (b) within a large repertoire of strategies, choose and apply a specific strategy, and (c) respond to feedback regarding the efficacy and outcome of the selected strategy, in order to change strategies if necessary (Bonanno & Burton, 2013). For example, suppressing laughter at funeral when remembering a funny anecdote, is considered adaptive (Bonanno & Burton, 2013; Elkjær et al., 2022). In EMA designs (e.g., Elkjær et al., 2022), flexibility has been assessed by calculating the intraclass correlation coefficient between different strategies across assessment points. If strategies are highly correlated or consistent over time, this suggests a lack of flexibility.

Executive Functioning, Stress Responses, Appraisals, and Affect Regulation

Affect regulation, along with its variability and flexibility, may be influenced by executive functioning, a multidimensional cognitive process enabling individuals to regulate thoughts and actions during goal-directed behavior (Friedman & Miyake, 2017). While its exact definition is debated, the Unity/diversity framework by Miyake and colleagues stands as a prominent model, identifying common and separate facets of executive functioning (for a review, see Baggetta & Alexander, 2016; Friedman et al., 2008; Friedman & Miyake, 2017; Miyake et al., 2000). This model includes inhibition, cognitive flexibility, and updating, and it highlights how these components contribute to differences in goal maintenance and management (Friedman & Miyake, 2017). Inhibition involves suppressing inappropriate responses and dealing with interference, while cognitive flexibility enables task set selection and goal switching (Barkley, 1997a; Brocki & Bohlin, 2004; Miyake & Friedman, 2012, 2017). Updating monitors incoming information and removes irrelevant content from working memory (De Lissnyder et al., 2010).

Working memory capacity is a separate, limited system responsible for temporarily storing and manipulating current task information (Baddeley, 2017). According to the multi-component model of working memory, executive functioning serves as a central component regulating a series of sub-processes within the working memory system (Baddeley, 2000). These functions not only allow for rapid responses to environmental changes, but also enable problem-solving and perspective-shifting in everyday life (Karbach & Unger, 2014).

There has been extensive research striving to understand the complexity of the relationship between stress and executive functioning. A large part of the literature has reviewed the impact of both acute and chronic stress on various facets of executive functioning facets (e.g., cognitive flexibility, inhibition, updating), and has also investigated the mechanisms at play in this association (e.g., Plieger & Reuter, 2020; Tsai et al., 2019). An alternative approach is to consider the protective role of executive functioning against sustained stress responses (as evidenced from Chapters 2-4). In EMA studies, researchers have recently been interested in this question. Benson and colleagues (2023) assessed working memory capacity through brief ambulatory assessment several times a day during seven days. They found that individuals presented greater negative affect reactivity to stressors when their working memory capacity was lower than usual, compared to their mean. Rónai and colleagues (2024) also found that when individuals have stronger momentary working memory updating abilities, they tended to experience reduced negative emotions following recent unpleasant events. However, increases in working memory updating was associated with heightened negative emotional reactions to events rated as more unpleasant. Currently, other facets of executive functioning and the potential underlying mechanisms involved have yet to be comprehensively studied.

While the studies on executive functioning and stressor appraisals are currently limited to laboratory studies (e.g., Zandara et al., 2016), and inexistent in EMA research, theoretical works suggest the relevance of studying this relationship. For example, creating an appraisal of a stressful event can either be rapid and instinctive, or deliberate and thoughtful with careful consideration of various perspectives before responding (Lazarus, 1999). In the laboratory, baseline updating was negative correlated with cognitive threat appraisals of the induced stressor (Zandara et al., 2016). Executive functioning – and cognitive flexibility, particularly – may be particularly relevant for deliberate appraisal processing. For example, cognitive flexibility may be involved in generating multiple appraisals across different situations (Fisher et al., 2019; Gabrys et al., 2018). Beyond producing individual appraisals, executive functioning may also be specifically involved in reappraisal and other affect regulation strategies.

Executive functioning has been proposed to share common neurobiological substrates with affect regulation strategies (e.g., Zelazo & Cunningham, 2007). Thus, affect regulation is believed to rely on various executive functioning facets, including cognitive flexibility, inhibition, and updating (Hofmann et al., 2012; Schmeichel & Tang, 2015).

Furthermore, the link between cognitive flexibility – as defined from a neuropsychological point of view – has seldom been integrated with emotion regulation flexibility approaches (Philippot et al., *in prep*.). In the cognitive control framework for emotion regulation flexibility, Pruessner and colleagues (2020) emphasize the role of executive control for (a) switching or discontinuing certain strategies, (b) maintaining strategies, and (c) monitoring the situation and the implementation of these strategies. Recently, Toh and Yang (2024) employed a latent-variable approach with an extensive battery of executive functioning tasks to explore the relationship between different facets (common executive functioning, working memory-specific, and shifting-specific factors) and the flexible adaptation and switching of emotion regulation strategies in response to stimuli of differing emotional intensity. In high-intensity contexts compared to low-intensity ones, better working memory was associated with greater emotion regulation variability and more frequent switching between strategies. In contrast, Eldesouky and English (2018) found that better inhibition and working memory predicted lower daily choice of emotion regulation strategies. Despite contrasting evidence on the subject, EMA offers new opportunities to assess affect regulation flexibility and to integrate the implications of executive functioning in this process.

Existing research is limited by a lack of studies that integrate different executive functioning facets into their designs. Moreover, current studies on executive functioning and stress often fail to incorporate measures of both stressor reactivity and recovery indices as recently proposed. Additionally, testing executive functioning and affect simultaneously at each beep in EMA designs makes it difficult to disentangle their mutual influences. Therefore, this study aimed to extend previous findings by adopting a multifaceted approach to both executive functioning and stress responses. In this approach, executive functioning – encompassing cognitive flexibility – was assessed at baseline, prior to the EMA design, allowing for a clearer analysis of its association with stress in daily life.

The Present Study

This study examined the relationship between executive functions (inhibition, cognitive flexibility, and updating), working memory capacity, and daily stress. We investigated the extent to which executive functioning predicted subjective stress reactivity and recovery from stressors that arise spontaneously in daily life. Additionally, we also examined the mediational role of stress appraisals and affect regulation. All hypotheses were pre-registered on OSF (https://osf.io/j6tvw) and ethical approval was obtained from the UCLouvain-St Luc Biomedical Ethics Committee. All hypotheses or analyses that deviate from these are explicitly stated as such. For example, given the low number of stressors reported per participant (see Table 8), we decided against combining stress scores at the day level.

Study Hypotheses

Executive Functioning and Daily Stress

We hypothesized that individuals with stronger executive functioning and working memory capacity at baseline would exhibit lower levels of stress affect. Perceived stress was calculated by averaging three items when exposed to a stressor: stress, nervousness, and tension. Building on our prior findings (Grimm & Agrigoroaei, 2023, 2024), we hypothesized that cognitive flexibility would emerge as the most relevant executive functioning facet to significantly predict this construct.

Table 8. Descriptive Statistics for Sociodemographic Variables, Executive Functioning, and Ecological Momentary Variables

Variable	Mean (SD)
Sociodemographic Variables	
Age *M(SD)*	22.42 (3.77)
Gender, *N(%)*	
Women	64 (65.98)
Men	33 (34.02)
Years of Education	15.73 (2.66)
Handedness, *N(%)*	
Right-handed	91 (93.81)
Left-handed	6 (0.06)
Ambidexter	0 (0.00)
Chronic Stress	14.90 (6.04)
Executive Functioning	
Cognitive Flexibility	660.8 (437.19)
Inhibition	201.17 (44.11)
Updating	0.88 (0.13)
Working Memory Capacity	43.07 (17.88)
EMA Variables	
Stressors	4.11 (3.21)
Stress emotions	
When stressful event present	45.31 (26.01)
When stressful event absent	19.56 (20.56)
Proximal Reactivity	27.68 (17.11)
Cumulative Reactivity	27.96 (16.39)
Proximal Recovery	-20.97 (16.43)
Cumulative Recovery	-5.83 (17.60)
Primary Appraisal	-0.16 (1.23)
Secondary Appraisal	2.93 (1.18)

Note. EMA = Ecological Momentary Assessment

Executive Functioning and Daily Stress Reactivity and Recovery

We anticipated that individuals with stronger executive functioning, particularly in cognitive flexibility, would experience less stress reactivity when they report encountering stressors. Additionally, we expected that these individuals would return to their normal stress levels more rapidly following the occurrence of a stressor. As we included indices of cumulative reactivity and recovery after the initial preregistration, our hypotheses now extend to these two concepts.

Executive Functioning, Appraisals, Affect Regulation, and Daily Stress

We predicted that executive functioning and working memory capacity would be associated with lower levels of perceived threat regarding the stressor (primary appraisal) and higher levels of perceived control (secondary appraisal). Regarding affect regulation strategies, we anticipated that executive functioning and working memory capacity would predict reduced tendencies towards avoidance and rumination, alongside increased use of reappraisal, planning, and active coping.

Exploratory Analyses: Affect Regulation Variability and Flexibility

We have tentative hypotheses although findings in the literature are decidedly mixed. We explored – with no a priori hypotheses – the potential involvement of executive functioning in the social sharing of emotions. We also expected that working memory capacity to be associated with lower affect regulation variability and flexibility. Although this has not been previously reported, the overlapping conceptualization of flexibility prompted us to expect an association between cognitive flexibility, as measured using a set-shifting task, with indices of affect regulation variability and flexibility. Better inhibition and working memory should also be related to lower daily engagement with affect regulation strategies.

5.2. Method

Participants

The sample size was determined using the ema.powercurve function within the *EMAtools* package (Kleinman, 2017) on RStudio (Version 1.4.1103). As a result, a sample size of 90 was deemed necessary to achieve a desired statistical power of .80, considering an average effect size (Cohen's d = .5), and anticipating an expected response completion rate of approximately 75% per participant. These calculations were based on six measurement occasions per day over seven days (resulting in 42 observations per person). To accommodate potential missing data and dropouts, a total of 120 individuals were recruited for this study.

The participants were recruited on a voluntary basis through advertisements posted on social media platforms (including research-specific groups) and through the psychology department, which forwarded the request to students enrolled in Psychology or Speech Therapy programs. The flyers were also sent to the Psychological Sciences Research Institute pool of participants, and participants were encouraged to discuss the study with their peers in a snowballing approach. Interested individuals completed a pre-selection questionnaire on Qualtrics (Provo, UT) to determine study eligibility. Inclusion criteria were being native French-speaking (or fluent before age 10), aged between 18 and 40, presenting no psychiatric or neurological disorders, and not having experienced unusual or severe stress in the month preceding the first day of the experiment. Additionally, volunteers were asked to have in their possession a smartphone with a working Internet connection. A total of 392 individuals partly or fully completed the pre-screening questionnaire, with 187 meeting all inclusion criteria and providing contact details. From these, a total of 120 participants were available and booked for testing.

Design and Procedure

Phase 1: Laboratory Testing

Data collection began in November 2022 and was completed in December 2023. Participants were welcomed to the laboratory for an initial one-hour individual testing session. Upon signing the consent form, they completed several questionnaires hosted on Qualtrics (Provo, UT), relating to sociodemographic information and chronic stress. Subsequently, participants completed four cognitive tasks measuring inhibition, cognitive flexibility, updating, and working memory capacity using Inquisit 6.5.8.1 (2021). Towards the end of the session, the experimenter explained the EMA procedure, installed the m-Path application (Mestdagh et al., 2023) on the participants' phones, and provided each with a user manual for study.

Phase 2: EMA

The EMA protocol was implemented over the following eight days, commencing with a "test" day, coinciding with the laboratory testing day. This allowed participants to familiarize themselves with the m-Path application (Mestdagh et al., 2023). After this, data collection extended over seven consecutive days, including two weekend days and five weekdays. Participants received six notifications daily, scheduled at fixed times in 2-hour intervals between 9:00 AM and 9:00 PM, employing a time-based occasion design. The application sent reminders after 15 minutes of no response, allowing participants to postpone their response if they desired. Thirty minutes after the initial notification, access to the questionnaire was no longer available. The application recorded the exact time of each response, with participants prompted to answer immediately upon notification.

At each beep, participants were first required to indicate their mood on several items at that present moment, then to indicate whether a stressful event had occurred since the last beep. If they responded yes, they further indicated stressor severity, stressor type, and time since stressor occurrence, as well as items regarding stress appraisals and affect regulation strategies. Due to the limited number of items included per questionnaire, each beep required maximum 2 to 5 minutes from the participant. The experimenter had access to the degree of completion of EMA questionnaires for each participant, and the experimenter could contact any participant with a low completion rate to discuss why they were having difficulties with the study protocol.

Phase 3: Study Completion and Debriefing

Upon completion of these questionnaires, participants were provided with a debriefing sheet outlining the study's objectives, specific hypotheses, and expected results. Financial compensation proportional to their study completion was provided to participants at the conclusion of the study (at most 25 euros).

Measures

Baseline Person-level Measures

Online Questionnaires

The online questionnaires and laboratory tasks administered are identical to those of Chapters 3 and 4.

Sociodemographic Questionnaire. Participants completed information regarding age, gender, years of education, and handedness (right-, left-, or ambidexter).

Perceived Stress Scale. To account for chronic stress present in the past months, the Perceived Stress Scale was administered. The scale demonstrated strong internal consistency, with a Cronbach's alpha coefficient of .85 and McDonald's omega of .85.

Cognitive Tasks

Inhibition. The Stop Signal Task was administered following recent guidelines (Verbruggen et al., 2019). The Stop-Signal reaction time was computed automatically using the integration model in Inquisit Lab. However, the race model was not met for three participants, as their reaction times on Stop-Signal trials exceeded those on successfully inhibited Go trials. Another participant had p(respond|signal) values falling outside the recommended range of 0.25 to 0.75 (Verbruggen et al., 2019). Hence, the scores for these individuals were marked absent from the database.

Cognitive Flexibility. In the Letter-Number Task (Miyake et al., 2000), trials with response times below 200ms and trials immediately following errors were excluded from further analysis. As a result, the average percentage of trials eliminated was 0.24% (SD = 8.51). The switch cost was computed as the difference between the average correct response times of switch trials and non-switch trials within the combined block

(Friedman et al., 2008). A positive value indicates a longer time required to switch between the two tasks.

Updating. The dependent variable used from the Letter Memory Task (Friedman et al., 2008) was the proportion of correctly recalled letters across all test trials.

Working Memory Capacity. Participants completed the Automated version of the Operation Span Task (Conway et al., 2005), which involves alternating between a letter memory test and mathematical problems. Consistent with prior suggestions (Unsworth et al., 2005), operation span scores for individuals with math problem accuracy below 85% were marked as missing from the database ($N = 4$). The Operation Span traditional score was derived from the sum of correctly recalled letters across all sets, with a maximum attainable score of 75.

Momentary Measures

Current Mood and Stress Levels

At every notification, participants judged the extent (0 =not at all to 100 =a lot) to which they felt, *at that moment*, ten emotion-related terms: tense, angry, relaxed, depressed, hostile, happy, nervous, sad, joyful, and stressed (Kramer et al., 2021). The items tense, nervous, and stressed were merged to evaluate overall feelings of stress at that moment. The within and between-Omegas were .84 and .97 respectively.

Stressor Occurrence and Intensity

At each notification, participants were asked whether a stressful event happened since the last beep. Based on work by the Science of Behavior Change (SOBC) program (Smyth et al., 2018), participants were asked whether a stressful event occurred since the last survey. A stressful event was defined as "any event, even a minor one, which negatively affected [the participant]." Participants answered yes or no. If they responded positively to this item, they were asked to select a stressor type (if more than one event occurred, then relating to the most significant one) between argument/conflict/disagreement, financial event, home-related event, work-related event, health event or accident, event that happened to others, traffic or transportation event, or other. Participants also provided information regarding the stressor timing (0-5 minutes ago, 5-10 minutes ago, 10-30 minutes ago, 30-60 minutes ago, 60+ minutes ago) and stressor intensity (ranging from 0 = not at all unpleasant to 100 = extremely unpleasant).

Stress Appraisals

Based on previous work (Sicorello et al., 2021), participants were asked the extent to which the event represented, for them, a threat (-3) or challenge (+3; i.e., primary appraisal). Following this, they completed another item evaluating the extent to which they felt in control of the event from 1 (not at all) to 7 (a lot, i.e., secondary appraisal).

Affect Regulation

The following items measuring different affect regulation strategies were selected from the Experience Sampling Methodology Repository (Kirtley et al., 2023): rumination, solution-seeking, acceptance, attentional avoidance, thought suppression, social sharing of emotions, active coping, reappraisal, emotional suppression, and reflection (see Table S1 in the Supplementary Materials for full item description). Participants were asked to report the extent to which they applied this strategy in light of the stressor, from 1 (not at all) to 7 (a lot).

Data Analysis

Indicators of Stress Reactivity and Stress Recovery

All calculations are based on the everyday stress components approach (Almeida et al., 2020; Marcusson-Clavertz et al., 2022; Smyth et al., 2018, 2023). For both reactivity and recovery, we conducted the required data cleaning and calculations for proximal and cumulative indices in Microsoft Excel.

Proximal Reactivity

Proximal reactivity, assessed by the "proximal baseline state" (Figure 16A), examines stress levels in observations just before the stressor (i.e., time *t-1*). Reactivity is calculated by subtracting the proximal baseline from stress levels at the stressor moment (time *t*). For example, if a participant had a negative affect score of 6 at the stressor moment and 2 at the non-stressor moment just prior, the proximal reactivity would be +4[1]. This score indicates whether current stress levels significantly differ from those a few hours ago (e.g., based on the prior non-stressor EMA report). Logically, proximal reactivity indices could not be computed for stressors if they occurred on the first beep of the day.

Cumulative Reactivity

Another approach to reactivity is using a cumulative baseline as reference point (see Figure 16B). All preceding non-stressor observations leading up to the stressor were aggregated to compute a cumulative baseline for stressor responses if they met either of the following criteria:

1. The observation occurred on a stressor-free day;
2. The observation was on a day with stressors but occurred before the first reported stressor.

Cumulative baselines were determined by averaging stress levels on all non-stressor moments meeting these criteria. This led to a significant reduction in data, given that days

[1] We removed negative values, as we deemed these not relevant for the concept reactivity.

that began with stressors could not be used. Cumulative reactivity was calculated by subtracting the cumulative baseline from stress levels at the stressor moment (time *t*). For example, if the stress levels at the stressor moment were 7 and the running average of stress levels on prior stressor-free assessments was 2, the cumulative reactivity for that moment would be +5. This state represents the mean level of a stress-response indicator from the beginning of the study up to the current day/moment, including only non-stressor observations that meet specific criteria for the windows (e.g., occurring on stressor-free days or before the first stressor of the day). This evaluates whether one's current stress levels significantly deviates from one's typical non-stressor state.

Proximal Recovery

Proximal recovery represented the immediate decrease in stress levels following a stressor, otherwise defined as "immediate recovery" (Figure 16C). This was calculated as the difference between stress levels at the stressor moment (time *t*) and at the subsequent non-stressor moment (time $t + 1$). For example, if stress levels at the stressor are 7 and that the subsequent non-stressor moment equal 2, the proximal recovery score would be -5. Lower recovery scores indicate a greater decrease in stress levels following the last stressor, regardless of pre-stressor stress levels. For interpretation purposes, these scores were reversed, as such that higher scores indicated greater decreases in stress affect from stressor to post-stressor occasion. Logically, proximal recovery indices could not be computed for stressors when (a) they were followed by another stressor and (b) they occurred on the last beep of the day. If two stressors immediately followed one another, we used the non-stressor levels following the second stressor as comparison baselines for both.

Cumulative Recovery

Cumulative recovery was computed as the difference between the stress levels for the cumulative baseline at the time of the stressor and the stress levels of the subsequent non-stressor assessment. This represents the extent to which stress levels have returned, fully or partially, to a resting state (*i.e.*, the cumulative baseline; see Figure 16D). A higher positive cumulative recovery score indicates a greater reduction in stress levels at the non-stressor assessment following the stressor compared to the cumulative baseline state, while a negative score suggests incomplete recovery (Smyth et al., 2023). For example, if the cumulative baseline at the time of the stressor indicates stress levels of 4 and the subsequent non-stressor moment shows a score of 1, the cumulative recovery score would be +3, indicating that the person's stress levels were 3 units below baseline. In contrast, if the subsequent non-stressor moment stress levels are at 8, the cumulative recovery score would be -4, indicating a failure to return to baseline. It is important to note that for each stressor moment, the same cumulative baseline was used to calculate cumulative reactivity and recovery relative to that moment. If two stressor moments succeeded one another, we calculated recovery as the difference between resting baseline levels prior to the first stressor and the stress affect at the stressor-free moment following the second stressor.

Indicators of Affect Regulation Variability and Flexibility

All indices were completed following calculations observed in prior research on coping flexibility and emotion differentiation (for all procedures, see Blanke et al., 2020; Elkjær et al., 2022; Erbas et al., 2018).

Endorsement of Adaptive and Maladaptive Strategies

Based on Elkjær and colleagues (2022) and Blanke and colleagues (2020), we calculated the indices separately for moment-based endorsement of “adaptive,” “maladaptive,” and overall affect regulation strategies. Adaptive emotion regulation regrouped the following strategies: acceptance, social sharing of emotions, active coping, solution-seeking, reappraisal, and reflection. Maladaptive emotion regulation was composed of attentional avoidance, thought suppression, emotional suppression, and rumination. As illustrated from the last column on Figure 17, mean endorsement represents the average intensity (i.e., on a scale from 1-7) with which the strategies were employed *at each measurement occasion* (the between-strategy mean). The mean overall endorsement was calculated by averaging the endorsement values across all occasions, resulting in a value of 1.94, as shown in Figure 17.

A

Beep No	S 1	S 2	S 3	S 4	S 5	S 6	*SD* Between	Mean endorse-ment
1	4	4	4	3	3	3	0.55	3.50
2	1	1	1	2	2	2	0.55	1.50
3	6	1	3	1	1	1	2.04	2.17
4	0	0	5	0	0	0	2.04	0.83
5	6	0	0	0	0	0	2.45	1.00
6	0	0	3	3	3	0	1.64	1.50
7	6	6	6	0	0	0	3.29	3.00
8	0	0	6	6	0	0	3.1	2.00
9	6	0	2	3	1	0	2.28	2.00
10	0	0	4	4	0	0	2.07	1.33
11	6	1	3	2	3	0	2.07	2.50
							2.01	**1.94**
***SD* Within**	2.93	1.99	1.91	1.89	1.33	1.04	**1.85**	

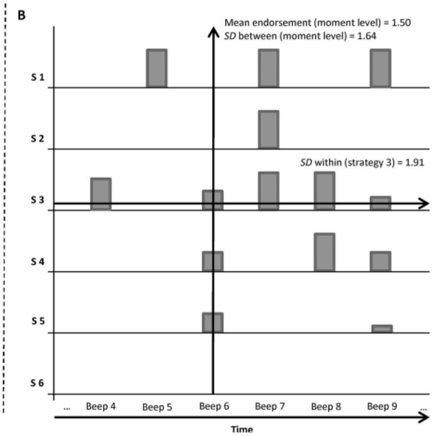

Figure 17. Illustration of within-strategy and between-strategy SD

Note. SD Within = within-strategy variability, SD Between = between-strategy variability. S = ER strategy. A: Fictious data from one person that rated six emotion regulation strategies on a scale from 0 to 6, displaying different means and SDs. Bold numbers denote person-level indicators. B: Illustration of beeps 4 to 9 from Panel A and the corresponding SDs. Figure copied from Blanke and colleagues (2020), with permission from the American Psychological Association.

The within- and between-omegas were calculated using the *omegaSEM* function from the “*multilevelTools*” package (Geldhof et al., 2014). The within and between omegas for endorsement of adaptive strategies were ω =.31 and ω =.71, respectively. The within and between omegas for maladaptive strategies were ω = .50 and ω =.79. Finally, the within and between omegas for all strategies grouped together were ω =.27 and ω = .85.

Variability Indices

We calculated variability indicators, both within and between variability in strategies, using standard deviations (*SD*; for full details on the procedure, see Aldao et al., 2015; Blanke et al., 2020; Elkjær et al., 2022). As illustrated in the last row of Figure 17, ***within-variability*** in affect regulation was calculated using the *SD* for endorsing one strategy across all stressor occasions as follows:

$$SD_{(within)i} = \sqrt{\frac{1}{N_i - 1}\sum\nolimits_{t=1}^{N_i}(x_{ti} - M_i)^2}$$

where for each individual i, there are N_i different measurement occasions or time points t. At each of these time points, the individual can apply one or more emotion regulation strategies, labelled s, where s ranges from 1 to L. The degree to which an individual uses a particular strategy s at time point t is represented by x_{sti}. For the mean within-strategy variability index, the *SD*s of each strategy were averaged for each individual:

$$M_{SD(within)i} = \frac{1}{L}\sum_{s=1}^{L} SD_{(within)si}$$

where a high level of overall within-strategy variability suggests that an individual employed all the considered strategies variably over time. The total number of strategies, L, remains the same for all individuals at each time point within the study.

Between-variability in affect regulation was calculated using the *SD* across all strategies for one stressor occasion, as illustrated in the second-to-last column in Figure 17:

$$SD_{(between)ti} = \sqrt{\frac{1}{L - 1}\sum\nolimits_{s=1}^{L}(x_{sti} - M_{(between)ti})^2}$$

As a person-level measure of between-strategy variability, the *SDs* between strategies (calculated at the moment-level) was averaged across all measurement occasions for each individual:

$$M_{SD(between)i} = \frac{1}{N_i}\sum_{t=1}^{N_i} SD_{(between)ti}$$

Higher values represent the fact that a few strategies are strongly prioritized. In contrast, lower values occur when either multiple strategies are endorsed to a similar extent or when only a few strategies are endorsed, but with low intensity.

We computed within- and between- variability for adaptive, maladaptive, and all emotion regulation strategies at the person level (*i.e.,* across all measurement occasions). These indicators were defined in relation to each person's mean, indicating variability beyond mean strategy used across all time points. For these to be calculated, participants were required to have reported at least two stressors throughout all beeps (N = 73, M stressors = 5.14, SD = 3.07).

Flexibility Indices

Flexibility in affect regulation was derived from work on emotion differentiation (Aldao et al., 2015; Elkjær et al., 2022; Erbas et al., 2018). In the latter, a nuanced emotional experience is marked by low correlation or consistency between emotions over time (Kashdan et al., 2015). We adapted the classic emotion differentiation index derived directly from the Inter-Class Correlation coefficients (Erbas et al., 2022). This captures the consistency of correlations between adaptive, maladaptive, and all affect regulation strategies across assessment points for each participant. The indicators reflect the convergence of strategies over time. Higher scores indicate *lower* differentiation (or in other words, greater difficulties in implementing different strategies).

The function "*calculate_ed*" from the R package "*emodiff*" (available on GitHub: https://github.com/seanchrismurphy/emodiff, "c_ed" returns the overall affect regulation differentiation index) was applied to the data. The package allows for the exclusion of negative ICCs (due to their unreliability; Giraudeau, 1996) and their transformation using Fisher's Z transformation (to correct for the non-normal distribution; Barrett et al., 2001). We multiplied the score by -1 for interpretation purposes, so that higher values indicate high levels of differentiation between strategies across all measurement observations.

However, due to low numbers of reported stressors (e.g., see Table 8) and limited variability in strategy engagement among some participants, we could only calculated ICCs for a portion of the sample (N = 38 for adaptive, N = 40 for maladaptive, and N = 38 for all strategies. For this reason, we only report correlational analyses, given the low statistical power: a G*Power a priori sample calculation revealed that regression analyses required a minimum of 55 to 85 individuals for testing one to four executive functioning facets as predictors of variability and flexibility of affect regulation.

Analytical Strategy

Pre-registered Analyses

All analytical procedures were pre-registered ahead of data collection on OSF (https://osf.io/q38fn). We realized that the estimated number of stress reports was overestimated in the initial power analyses. Moreover, new approaches to stress reactivity and recovery (e.g., cumulative baseline) were proposed by Smyth and colleagues (2023) since the pre-registration. Thus, the statistical approaches vary slightly compared to the latter. We outline these changes below. For continuous variables, means, standard deviations, medians, minimum, and maximum values were used to describe the variables, while categorical variables were described using mode, frequencies, and percentages. Descriptive analyses of all variables were conducted to assess the normality assumption of the data. We averaged the data across a person's measurement occasions to calculate correlations between executive functioning, mediators, and stress indices. We ran Pearson bivariate correlations between all normally distributed variables, as well as Spearman correlations with any non-normally distributed variable (e.g., cognitive flexibility, inhibition, updating, and proximal reactivity and proximal recovery). We also ran sensitivity analyses with and without outliers (N = 8). If the results changed when removing these outliers, we reported the results without them. For the associations in which Pearson and Spearman correlations did not produce different results, we reported the former only. Additionally, we calculated separate multilevel correlations between all level-1 variables using the R package "*correlation*" (Makowski et al., 2020). Removing outliers led to significant differences, thus we report the results without them.

We used the R package "*lme4*" (Bates et al., 2015) to compute linear mixed model fit by REML. Model 1 had stress levels (based on tense, nervous, and stress items) predicted by executive functioning facets (Hypothesis 1). In models 2 and 3, all four executive functioning facets predicted proximal and cumulative stressor reactivity. In models 4 and 5, the same facets predicted proximal and cumulative stressor recovery. All predictors were standardized to allow for an easier interpretation of the effects. We included a random intercept for individual participants. Gender and chronic stress levels were included as covariates across all models. We verified all model assumptions using the package "Dharma" (Hartig, 2018). It is important to note that while the model for stress reactivity passed the dispersion, deviations, and outlier tests, the KS test was significant (p = .010), and there were significant quantile deviations between residuals and predicted values for the lowest quantile (see Figure S1 in Supplementary Materials). When log-transforming the output, the effect of the inhibition score became significant but also led to all three quartiles showing significant deviations between residuals and predicted values. Therefore, we report the former results, only.

To examine the mediational role of appraisals and emotion regulation strategies, multilevel mediation models were completed using the *lavaan* package in R if (a) executive functioning facets significantly predicted the potential mediators and (b) if these were significantly correlated with one of the four stress indices. Participants with missing data were removed from analyses. Participant characteristics were compared between those with and without missing data and can be found as Supplementary Materials (Table S2). We report p-values and results were considered significant if $p < .05$.

Exploratory Analyses

We performed correlation and regression analyses to explore the association between executive functioning and each index of variability and flexibility of affect regulation.

Regression models included executive functioning facets as predictors, with gender and chronic stress as covariates. Nine regression models examined variability indices. We verified and corrected model assumptions, using log-transformations or addressing heteroscedasticity as needed. Original results are reported due to unchanged outcomes with the corrections. All possible observations for each outcome were used.

5.3. Results

Participants

A total of 120 individuals were recruited for this study. Ten participants were removed from data analysis due to at least one of these reasons: missing data at baseline (N = 2), violating the race model in the inhibition task (N =3), probability of responding on stop trials deviating significantly from 0.5 (N =1), making more than 11.25 mistakes on the Operation Span task (N = 4), or reporting no stressors in the EMA protocol (N = 14). No significant differences found between individuals with and without missing data (see Table S2 in the Supplementary Materials). The final sample was composed of 33 men and 64 women, aged 18 to 39, and presenting 12 to 23 years of education (see Table 8 and Table 9 for full descriptives). On average, the response rate to the beeps were 89.72%. Individuals reported one to 16 stressors (M = 4.08, SD = 3.18; from these, individuals spontaneously reported 0.62 stressors, SD = 0.93).

Descriptive Results

All correlations can be found as Supplementary Materials (Table S3). Poorer flexibility was associated with lower acceptance [$\rho(86)$= -0.25, p = .020)], lower reflection use [$\rho(86)$= -0.25, p = .019)], and higher rumination [$\rho(86)$= 0.26, p = .015)]. Better updating was correlated with higher solution seeking [$\rho(86)$= 0.25, p = .018)] and with general greater endorsement of adaptive strategies [$r(95)$= 0.24, p = .019]. Better working memory was associate with lower proximal stress reactivity [$\rho(89)$= -0.22, p = .033)], less change in proximal recovery [$\rho(93)$= -0.29, p = .004)], and higher solution seeking [$r(89)$ = 0.21, p = .035)].

Primary and secondary appraisals did not significantly correlate with any executive functioning facets (see Table S4). Higher perceptions of control predicted lower proximal recovery [$r(343)$= -0.16, p = .002; see Supplementary Materials (Table S4)].

With respect to affect regulation strategies, acceptance showed no consistent significant associations with any of the four stress outcomes. Reflection was significantly correlated with lower proximal reactivity [r (315) = -0.18, p = .001][2], lower cumulative reactivity [$r(143)$ = -0.20, p = .019]2, and lower change in proximal recovery [$r(379)$ = -0.12,

[2] The results were the same for Pearson and Spearman correlations, with and without outliers.

$p = .023$]. Rumination was significantly correlated with higher proximal reactivity [$r(315) = 0.19$, $p < .001$]. These two variables were retained as mediators.

Multilevel Models for Stress Reactivity and Recovery

We found a significant interaction effect between working memory and the occurrence of a stressful event (see Figure 18; Table S5). When participants reported stressful events, higher working memory capacity predicted lower stress affect. The opposite effect occurred when no stressors were reported. None of the linear mixed models predicting proximal and cumulative reactivity and recovery models found significant effects of executive functioning (see Table S6).

Table 9. Descriptive Statistics for Affect Regulation, Variability, and Flexibility

Variable	Mean (SD)
Affect Regulation	
Action	3.87 (1.35)
Solution	4.19 (1.61)
Acceptance	4.45 (1.33)
Reappraisal	3.73 (1.39)
Reflection	3.64 (1.45)
Social Emotions	3.62 (1.64)
Rumination	5.11 (1.06)
Avoidance	3.47 (1.42)
Thought Suppression	3.60 (1.48)
Emotion Suppression	3.21 (1.52)
AR Within-Variability (N = 73)	
Adaptive Strategies	1.60 (0.41)
Maladaptive Strategies	1.44 (0.56)
Overall	1.53 (0.39)
AR Between-Variability (N = 97)	
Adaptive Strategies	1.82 (0.45)
Maladaptive Strategies	1.68 (0.64)
Overall	1.87 (0.40)
AR Flexibility	
Adaptive Strategies	-0.67 (0.35)
Maladaptive Strategies	-0.81 (4.10)
Overall	-0.63 (0.27)

Note. *AR* = Affect Regulation; Higher scores indicate lower ICC's and, therefore, greater differentiation between strategies.

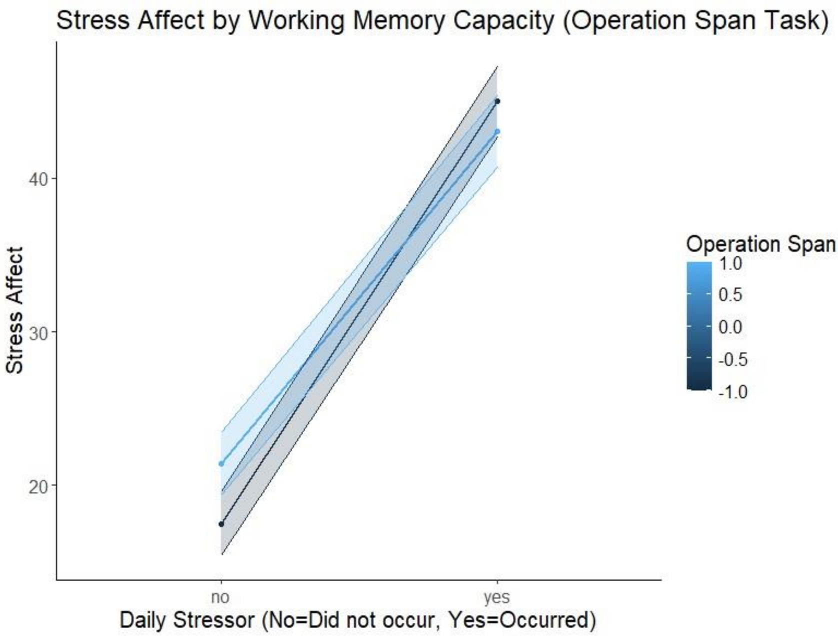

Figure 18. Interaction effect of Working Memory Capacity with Stress Affect Depending on the Report of a Stressful Event

Moreover, none of the structural equation models found evidence for significant mediation effects of reflection or rumination (see Table S7). While in some models, path a (i.e., lower flexibility predicting greater rumination) or path b (i.e., higher reflection predicting lower proximal recovery) were significant, none of the other respective model components were (see Table S7).

Exploratory Analyses on Affect Regulation Variability and Flexibility

Affect Regulation Variability

Poorer flexibility was significantly associated with greater within-variability in adaptive strategies [$r(71)= 0.25$, $p = .036$] and with greater between-variability in maladaptive strategies [$r(95)= 0.22$, $p = .031$; see Table S8][3]. Greater between-variability in maladaptive strategies was associated with less distal reactivity [$r(77)= -0.23$, $p= .042$] and less change in proximal recovery [$\rho(84)= -.22$, $p=.039$][4].

[3] The correlations change according to the method used but not when removing outliers, thus we report the findings for the complete sample in Supplementary Materials (Table S8).

[4] Correlations change when using Spearman compared to Pearson correlations, as well as when removing outliers or not. Therefore, we report the correlations without outliers.

Regarding the regression models, the only significant effect found for executive functioning was for inhibition and between-variability in adaptive strategies. Poorer inhibition (i.e., longer Stop-Signal Reaction Time) was associated higher between-variability in the strategies used for adaptive affect regulation (see Table 10 for the regression model and Supplementary Materials S9-S11 for all other models). However, there were no significant correlations between between-variability in adaptive strategies and any of the four stress indices, so no further mediational models were tested.

Table 10. Regression Model with Executive Functioning and Working Memory Capacity as Predictors of Between-Variability in Adaptive Strategies

	Between-variability Adaptive Strategies		
Predictors	*Standardized Beta*	*Standardized CI*	*p*
(Intercept)	**0.40**	**0.06 – 0.75**	**0.016**
Flexibility	0.11	-0.10 – 0.32	0.294
Inhibition	**0.23**	**0.03 – 0.43**	**0.023**
Updating	-0.13	-0.36 – 0.09	0.244
WMC	0.07	-0.15 – 0.28	0.541
Chronic Stress	0.09	-0.11 – 0.29	0.385
Age	0.12	-0.09 – 0.32	0.252
Gender	**-0.61**	**-1.05 – -0.17**	**0.007**
Observations	97		
R^2 / R^2 adjusted	0.174 / 0.109		

Note. CI = Confidence Intervals; *WMC* = Working Memory Capacity.

Affect Regulation Flexibility

There were no significant correlations between any of the executive functioning facets and strategy differentiation among adaptive, maladaptive, and all strategies (see Table S12). Better differentiation among maladaptive strategies was associated with lower cumulative reactivity [$r(36)= -0.34, p = .038$)[5] and better proximal recovery [ρ (38)= 0.33, p = .036][6].

5.4. Discussion

The aim of this EMA study was three-fold. First, it investigated the association between three baseline executive functioning facets (i.e., inhibition, cognitive flexibility, updating), as well as working memory capacity, with stress reactivity and recovery when facing daily stressors. Second, it studied the potential mediational role of stress appraisals and affect regulation strategies in the relationship between executive functioning and stress. Third, it integrated research on neuropsychological flexibility and emotion

[5] This effect disappeared when using Spearman correlations.

[6] This effect disappeared when using Pearson correlations.

regulation flexibility by examining the relationship between executive functioning and measures of affect regulation variability and flexibility.

Executive Functioning and Stress Reactivity and Recovery

Our first hypothesis was that better executive functioning would be associated with lower stress levels, as indicated by higher combined scores of stress, nervousness, and tension. Specifically, we expected cognitive flexibility (set-shifting) to be most relevant for predicting lower stress affect. Exploratory analyses revealed a significant interaction between working memory and the presence of stressors. Better working memory was associated with lower stress when participants reported a stressor. When participants did not report stressful events, greater working memory capacity at baseline was linked to increased feelings of stress. These findings suggest that better baseline working memory capacity may protect against excessive stress when encountering stressors. Our results align with previous EMA studies showing that *momentary* working memory capacity predicts lower negative emotions and stress (Benson et al., 2023; Rónai et al., 2024). These findings demonstrate that baseline working memory capacity can also play a protective role, reducing stress in response to daily stressors.

We also proposed specific pre-registered hypotheses regarding calculated indices of proximal and cumulative stress reactivity and recovery. We predicted that individuals with better executive functioning, especially cognitive flexibility (set-shifting), would exhibit reduced stress reactivity when encountering stressors. Furthermore, we anticipated faster recovery to baseline stress levels in these individuals after experiencing stressors. Contrary to these pre-registered hypotheses, however, the linear mixed models found no evidence for any of the executive functioning facets, tested at baseline, predicting pre-calculated indices of proximal and cumulative stress reactivity and recovery. While correlations indicated significant associations between better working memory and lower proximal stress reactivity and lower proximal recovery, these associations disappeared when accounting for other executive functioning facets in the regression models. Thus, our results do not support the role of executive functioning in stress responses when using recent conceptualizations for daily life (e.g., Almeida et al., 2020; Marcusson-Clavertz et al., 2022; Smyth et al., 2023). We discuss measurement issues regarding these indices in the limitations section.

Executive Functioning and Affect Regulation

Regarding primary and secondary appraisals, we expected executive functioning to correlate with lower perceived threat from stressors (primary appraisal) and higher perceived control (secondary appraisal). However, this hypothesis was not confirmed, and our results did not show a significant association between executive functioning and stressor appraisals in daily life. This aligns with previous findings (Panganiban & Matthews, 2014; Slattery et al., 2013; Zandara et al., 2016) and unpublished data (Grimm & Agrigoroaei, 2024), suggesting that executive functioning may not play a role in initial appraisals of stressors. Appraisals arise automatically in response to high situational demands (Lazarus & Folkman, 1984b), likely bypassing the effortful, top-down processes captured by executive functioning tasks. These processes may be more relevant later in the affect regulation process, when individuals attempt to cope with stressors. Future research could use attentional bias paradigms with eye-tracking to investigate the role of unconscious attentional biases in predicting these appraisals.

In terms of affect regulation strategies, we anticipated that executive functioning would predict decreased tendencies for avoidance and rumination, and increased use of reappraisal, planning, and active coping. These hypotheses were only partially confirmed. Better updating was significantly associated with higher use of solution-seeking and general endorsement of adaptive strategies. Worse cognitive flexibility (set-shifting) was also significantly correlated with lower acceptance of the situation, lower reflection, and higher rumination use. These findings suggest that different executive functioning facets influence various affect regulation strategies, aligning with previous research models and theories (Hofmann et al., 2012; Schmeichel & Tang, 2015). Overall, better executive functioning was linked to higher use of strategies generally considered adaptive (e.g., acceptance, solution-seeking, reflection), though different facets influenced different strategies. However, it is important to note the limitations of these correlational findings and that they do not indicate the success of these strategies in achieving desired outcomes.

The multilevel mediation models did not find significant mediation effects of affect regulation strategies between executive functioning and stress reactivity or recovery. Despite significant correlations between certain strategies and stress response indices, there was no overall significant mediation effect. This suggests that while executive functioning influences the use of certain strategies to manage stressors, these strategies do not account for the association between executive functioning and stress responses. Further research is needed to replicate these findings with different stress response measurements to confirm the absence of these effects, including physiological markers.

Executive Functioning and Affect Regulation Variability and Flexibility

Regarding the exploratory work on variability and flexibility in affect regulation, we anticipated that both cognitive flexibility (set-shifting) and working memory would correlate with decreased variability and flexibility of affect regulation. Poorer flexibility (i.e., higher RT switch costs) was significantly correlated with greater within-variability in adaptive emotion regulation strategies and greater between-variability in maladaptive strategies. In previous studies on emotion regulation strategies, these were associated with greater psychological distress and lower satisfaction with life (Elkjær et al., 2022). Potentially, these could be associated with negative outcomes for one's mental health. However, our preliminary results are limited by their correlational nature.

Across all regression models, the only significant association was between poorer inhibition and greater variability in adaptive affect regulation strategies. Individuals with worse inhibition showed more variability in their use of adaptive strategies for each stressful event, likely selecting some adaptive strategies over others at each new stressor (Elkjær et al., 2022). However, the impact of this variability on subsequent stress responses remains unclear. Previous research had reported that a greater repertoire was associated with more positive, adaptive outcomes, depending on the types of strategies used (Cheng et al., 2014; Southward et al., 2018). As stated previously, Elkjær and colleagues (2022) found that higher between-variability in adaptive emotion regulation strategies was associated with lower well-being. In our study, however, between-variability in adaptive strategies was not significantly correlated with the stress indices. Based on existing research, however, it may be that poorer executive functioning is associated with lower use of adaptive strategies and, ultimately, poorer mental health. Due to the absence of significant correlations between this type of variability and any stress indices, no mediational models were computed. Overall, cognitive flexibility and inhibition appeared particularly relevant for within- and between-variability in affect regulation strategies. However, future studies should strive to replicate these effects in larger samples, while also accounting for the possible mediating effects.

Finally, contrary to our predictions, there were no significant correlations between any of the executive functioning facets and strategy differentiation indices. Higher differentiation among maladaptive strategies was associated with lower proximal recovery. Previously, adaptive emotion regulation flexibility negatively predicted well-being (Elkjær et al., 2022), suggesting that it may be more beneficial for individuals to use the same adaptive strategies across different stressors. Our results, focusing on flexibility in *maladaptive* strategies, indicate that more varied implementations of these strategies may be associated with lower decrease in stress affect when recovering from a stressor. Therefore, these findings extend those of Elkjær and colleagues (2022), suggesting that better flexibility – regardless of the type of strategies it concerns – may not necessarily lead to positive outcomes for stress. These findings also contribute to the ongoing debate about labeling strategies as simply adaptive or maladaptive (Aldao et al., 2015; Bonanno & Burton, 2013; English & Eldesouky, 2020). In the context of daily stressors, more flexible use of maladaptive strategies across different stressors may limit recovery from stressors. While these preliminary results provide interesting knowledge linking cognitive flexibility to emotion regulation flexibility, it is essential to highlight that these remain correlational.

Study Strengths, Limitations, and Perspectives

The strengths of the current design include the multidimensional approach to executive functioning, the use of EMA to account for novel indices of both stress reactivity and recovery, as well as for emotion regulation variability and flexibility. Another strength involves the use of event-based sampling. Participants were invited to provide data regarding “spontaneous” stressful events. This enhanced the representation of different stressful contexts, rather than solely relying on fixed or random prompts (i.e., interval- or signal-contingent sampling; English & Eldesouky, 2020).

Despite the novel approach bridging executive functioning, stress responses, stressor appraisals, and affect regulation, several limitations must be mentioned. First, the calculations to capture stress reactivity and recovery are not perfect. An overview of strengths and weaknesses of the selected indices are provided by Smyth and colleagues (2023) and must be considered when interpretating the results. In non-experimental ecological settings, it is impossible to entirely separate experiences with stressors from those without them, questioning the extent to which reactivity captures a truly “pure” measure of change in affect (Marcusson-Clavertz et al., 2022). Similarly, De Calheiros Velozo and colleagues (2023) propose that reactivity scores are, in fact, capturing recovery processes. In EMA, the notification to measure stress affect is likely to occur after the initial peak of stress reactivity, during recovery. In support of this, they found that self-reported measures of stress 15 minutes after the induction of a psychosocial stressor in the laboratory (i.e., recovery) was the strongest predictor of affective stress reactivity in daily life (using EMA). However, they did not find such significant associations between heart rate, Root Mean Square of Successive Differences and skin conductance levels. Finally, our measure of proximal recovery only captures negative change from a stressor moment to the next non-stressor occasion, omitting instances where individuals potentially felt worse at the next non-stressor moment. As a result, it captured the degree of change in stress affect, which may be proportional to that of proximal reactivity.

To overcome these limitations, researchers are encouraged to include longer time windows for capturing physiological measures in EMA designs and to incorporate event-contingent sampling designs, the latter of which was implemented in the current study (De Calheiros Velozo et al., 2023; Smyth et al., 2023). Additionally, ambulatory tools that record ambient and contextual information, such as audio snippets using the electronically activated recorder (Mehl et al., 2001), as well as concurrent physiological measures (e.g., heart rate variability, cortisol) could provide complementary information beyond self-report to the calculations of stress responses in daily life.

Another general limitation to this study was the use of single items to capture appraisal and separate affect regulation strategies. It is important to note, however, that we carefully selected the items based on pre-existing literature and matched these to the available items in the EMA repository (Kirtley et al., 2023). This ensured the gathering of strong items to represent the chosen strategies and reduced participant burden by limiting the number of questions at each beep. If one were to capture more nuanced appraisals, however, the modified Stressor Appraisal Scale (Gartland et al., 2012) comprising five items measuring primary appraisals and three items measuring secondary appraisals could be administered as an alternative.

Finally, it is important to recognize limitations in the measurement of affect regulation strategies. First, this study only focused on negative emotions in response to stressful events. However, EMA studies have found that the frequency in choosing an affect regulation strategy is also dependent on the emotion being processed, and that it could be relevant to also focus on positive affect changes (Heiy & Cheavens, 2014). Second, we did not account for the social aspects of emotion regulation, though we know that the presence of others may influence affect regulation choice (English & Eldesouky, 2020). Third, emotional regulation should also consider goal-relevant information. While straightforward mappings between strategy and goal might not universally apply, certain strategies are more conducive to achieving goals within specific contexts (e.g., as discussed by Aldao et al., 2015; Elkjær et al., 2022). For example, strategies based on emotion expression (e.g., suppression) may vary more based on cues related to social connections (e.g., presence of others, social environment) than cues related to competence (e.g., workplace dynamics). Suppression may also be more effective in emotionally intense contexts (Sheppes et al., 2011), while reappraisal appears more beneficial when faced with uncontrollable stressors. Better reappraisal has been associated with lower levels of depression following a stressful event perceived as uncontrollable, but with higher subsequent depression if the stressor was perceived as controllable (Troy et al., 2013; see review by Colombo 2020). This highlights the importance of strategy-fit, suggesting that certain strategies are better suited for specific situations, and that these should be considered in future research designs. Fourth, acknowledging context may also aid in understanding what these variability indices capture. Rather than indicating effective attainment of desired emotional states or personal goals, employing a range of strategies could merely signify a trial-and-error approach, potentially lacking in regulation success (Elkjær et al., 2022). Future research should incorporate assessments of whether the intended emotional state or personal goal is achieved, to determine whether flexibility and variability in affect regulation are genuinely adaptive. Fifth, insights into affect regulation could be drawn from other studies on emotion dynamics (Kuppens & Verduyn, 2017). For instance, metrics like mean squared successive differences (reflective of emotional instability in response to the environment) and inertia (indicating inflexible emotions) could be expanded to assess flexibility (English & Eldesouky, 2020). Given the novelty of the field, there are ample opportunities to reassess traditional measures of flexibility and incorporate alternative metrics.

5.5. Conclusion

To conclude, exposure to acute stressors in everyday life can generate significant stress responses. The aim of this study was to evaluate whether inhibition, cognitive flexibility, updating, and working memory capacity could help prevent excessive reactivity and promote faster recovery to daily stressors. Overall, the results provided limited evidence for a direct association between executive functioning and stress. Working memory capacity was correlated with lower proximal reactivity and lower proximal recovery, though this did not stay significant in regression models. Working memory capacity also significantly interacted with stressful events, as such that higher scores predicted lower stress affect when exposed to stressors. Furthermore, there were no significant associations between executive functioning and any cognitive appraisals. Meanwhile, poorer cognitive flexibility was significantly associated with higher rumination and lower reflection in response to stressors, but none of these variables significantly mediated the effect between executive functioning and stress reactivity and recovery. Moreover, poorer cognitive flexibility was also associated with greater within-variability in adaptive strategies and between-variability in maladaptive strategies. In the regression models, poorer inhibition significantly predicted greater between-variability in adaptive strategies. Finally, there were no significant associations between executive functioning and affect regulation flexibility. Given these mixed results, we question the relevance of executive functioning for stress and its regulation in the context of daily life.

Section 3.

Affective flexibility: what role for emotional material?

Chapter 6.

Affective Flexibility for Stress Responses: Investigating Appraisal and Affect Regulation Strategies

The present article investigated the associations between affective flexibility and stress regulation in two independent studies. In Study 1, participants completed a set-shifting paradigm measuring affective flexibility and were then randomly assigned to an experimental (*N* = 87) or a control (*N* = 43) version of the Maastricht Acute Stress Test. Measures of self-reported stress, negative and positive affect, appraisal, and affect regulation were administered before and after the stress induction. Individuals with better flexibility switching to the affective processing of negative stimuli presented higher use of suppression during the stressor and lower self-reported stress following the induction. In Study 2, university students (*N* = 123) were administered the same affective flexibility task approximately two months before the first examination of end-of-year session. One week before their first examination, they completed measures of anticipatory stress, appraisals, coping strategies, and worry ahead of the impending session. Better flexibility switching to the affective aspects of negative stimuli was associated with higher appraisals of uncontrollability, while better flexibility switching to the non-affective processing of positive stimuli was related to lower self-reported stress and greater use of maladaptive coping. These findings identify a separated effect of flexibility for emotional and behavioral responses to stressors: while better flexibility is linked to more "adaptive" emotional responses, it is less so for appraisal and affect regulation choices. Aligned with recent frameworks of emotion regulation flexibility, we argue for the importance of considering context when evaluating affective flexibility and affect regulation as "(mal)adaptive".

Reference

Grimm, E., Mas, M., Agrigoroaei, S. & Luminet, O. (2024) *Affective Flexibility for Stress Responses: Investigating Appraisal and Affect Regulation Strategies*. Internal UCLouvain report: unpublished.

6.1. Introduction

Cognitive flexibility can be defined as an emergent property of cognition (Dajani & Uddin, 2015) that allows individuals to switch between tasks, operations, actions, or cognitions, in light of new information or demands (Diamond, 2013). Its implementation relies on cognitive processes including executive function (inhibition, shifting, working memory) and attentional processes such as, salience detection (Dajani & Uddin, 2015). Deficits in flexibility – or, higher *inflexibility* – have been observed in a number of mental disorders (Grant & Chamberlain, 2023). Better cognitive flexibility is also associated with positive outcomes, including problem-solving (Ionescu, 2012) and resilience (Genet & Siemer, 2011).

Resilience is a dynamic process that allows individuals, when faced with adversity, to experience a stress response (i.e., stress reactivity) and a subsequent recovery process to baseline levels (Arnold et al., 2023; Madison, 2021; Rademacher et al., 2023). These physiological and subjective stress responses facilitate one's adaptation to these situations (Epel et al., 2018). When these acute stress responses become repeated and sustained, they can negatively impact one's health. Examples of these responses include the persistent anticipation of future events, under- or over-pronounced reactivity, prolonged recovery times, and a lack of habituation upon repeated exposure to similar stressors (Epel et al., 2018). Such maladaptive activations lead to long-term consequences for the organism. Chronic exposure to stressors and its consequential sustained physiological arousal provokes a cumulative "wear-and-tear" of the body and of its physiological systems (McEwen, 1998). Ultimately, this leaves the organism more susceptible to stress-related diseases and disorders (Lupien et al., 2015). Consequently, it is imperative to identify modifiable clinical targets that can mitigate inadequate stress responses.

Cognitive flexibility has been theorized to play a role in promoting better stress regulation (Haglund et al., 2007; Rademacher et al., 2023). For example, improved task-switching performance has previously been significantly associated with lower skin conductance reactivity to a laboratory-induced stressor (Hendrawan et al., 2012; for a systematic review and meta-analysis, see Grimm et al., 2021). Flexibility is often evaluated using set-shifting or task-switching paradigms involving *neutral* stimuli (for reviews of existing tasks, see Hohl & Dolcos, 2024; Kupis & Uddin, 2023). However, responses to stressful events often implicate deficits in processing *affective* information, such as negative affect or increased negative thoughts (Brosschot et al., 2006). Thus, considering the flexible control of emotional material would be more relevant for studying its impact for stress responses.

Affective Flexibility

Affective flexibility is defined by Genet and Siemer (2011) as the "ability to switch back and forth between processing the *affective* versus *non-affective* qualities of affective information." This concept has been explored in relation to resilience and lab-induced stress. Studies in the context of resilience have found that higher cognitive flexibility *and* affective flexibility were significantly associated with higher resilience as measured using questionnaires (Genet & Siemer, 2011). More recently, Rademacher and colleagues (2023) replicated this effect, though only the switch costs calculated for the *affective* task remained significant predictors of resilience when both cognitive and affective switch costs were included in the regression model. This indicates that better flexibility in switching between affective and non-affective material explained more variance in predicting resilience, as opposed to switching between neutral stimuli. Thus, accounting for the valence of the processed material when one switches tasks appears to be particularly important for the study of stress and resilience.

In the context of stress reactivity in the laboratory, however, Grol and De Raedt (2021) failed to find an effect of affective flexibility on stressor-induced changes in positive ("happy" item) or negative emotions (as measured with a combined "sadness" and "anger" items), nor on a physiological measure of stress (heart rate variability). However, the implications of these findings are restricted by the absence of a control group, limited measures of affect, a reliance on induced stress in controlled settings, and the need for replicability. Beyond the scarce research on affective flexibility and stress, even less is known on potential mechanisms involved, such as appraisals and affect regulation.

Affective Flexibility and Stress Responses: Unravelling the Resilience Mechanisms at Play

Appraisal

Affective flexibility may influence how individuals react both cognitively (*i.e.*, appraisals of the situation) and behaviorally (*i.e.*, affect regulation and coping strategies) to stressors. To begin with, appraisals are key mechanisms of resilience, as they determine the magnitude of initial subjective, physiological, and emotional response(s) to stressful situations (Fisher et al., 2019; Lazarus & Folkman, 1984b; Scherer & Moors, 2019). They involve "weighing different aspects of a situation against idiographic goals on a relatively small set of appraisal dimensions to optimize one's response to situational demands" (Everaert et al., 2021). In the context of stress research, imbalances between one's perception of situational demands (primary appraisals) and perceived coping options and resources (secondary appraisals: Lazarus & Folkman, 1984) is known to impact subsequent strategy choice (e.g., Schmidt et al., 2010) and have long-term effects for mental and/or physical health (e.g., Gomes et al., 2013).

However, research on cognitive – let alone affective – flexibility and stressor appraisals is scarce. In a commentary on appraisal theories, Kuppens (2013) emphasized the important role of flexibility in not only how appraisals are created, but also how they relate to other parts of the continuous dynamic process of emotions (e.g., physiological responses, emotions, behaviors…). Experimental designs investigating such flexibility are lacking. Where other components of executive functioning have been studies, better working memory was associated with lower threat appraisals of an induced laboratory stressor (Zandara et al., 2016). Thus, beyond its innovative importance, investigating affective flexibility may also clarify how the flexible processing of emotional content is involved in the generation of different appraisals to a stressor.

Affect Regulation

In addition, affect regulation strategies refers to the strategies that are implemented to modulate one's physiological and subjective responses to stressful events (Troy et al., 2023). This encompasses notions of both coping and emotion regulation. Strategies include situational change (*e.g.,* situation selection and modification; problem-focused or active coping), attentional deployment (*e.g.,* distraction or disengagement coping), cognitive change (e.g., reappraisal or acceptance), and response modulation (*e.g.,* expressive suppression). These resilience mechanisms aid in limiting the initial stress response and in promoting a rapid return to baseline levels (Arnold et al., 2023; Fisher et al., 2019).

Cognitive and affective flexibility may be particularly involved in *re*appraisal, as this entails inhibiting initial appraisals, generating and maintaining non-emotional appraisals in working memory, and transitioning between initial and more suitable appraisals (Pierce et al., 2022; Schmeichel & Tang, 2015). Pruessner and colleagues (2020) recently proposed a Cognitive Framework of Emotion Regulation Flexibility. They suggest that such flexibility requires (a) identifying whether emotion regulation is required, (b) selecting appropriate strategies, and (c) implementing the chosen strategy. They further argue that executive functioning is key for strategy stopping or switching, strategy maintenance, and monitoring its efficiency. More specifically, cognitive flexibility, as measured using task-switching paradigms, is theorized to be involved in switching mental sets to "either initiate an alternative ER strategy (described as "means shifting"; Hofmann et al., 2012) or to discontinue the regulatory process and switch to another action (characterized as "goal shifting"; Hofmann et al., 2012, as cited by Pruessner et al. 2020). A deficit in flexibility may also lead to difficulties disengaging from negative thoughts and behaviors that may lead to the perseveration of these in working memory (e.g., De Lissnyder et al., 2012; Genet et al., 2013), and, therefore, sustained negative mood. To understand how these processes may be implicated in stress regulation, we review the existing research on affective flexibility.

Affective Flexibility: A Review of Existing Results

An important proportion of studies in the field of affective flexibility have implemented a specific task-shifting paradigm with positive and negative images (Genet et al., 2013; Malooly et al., 2013). In this paradigm, individuals view stimuli and are instructed to sort them either according to an affective rule (i.e., whether the image is positive or negative) or a non-affective rule (i.e., whether there are one less or two or more individuals in the picture). The task captures different switch costs from non-affective to affective rules (and vice versa), in the context of processing either negative and positive images (for an overview of the switch costs calculations, see Table 16). To date, studies have found differing switch costs to be associated with anxiety, rumination, worry, and emotion regulation depending on the valence of the material being processed (see Table 11 for a review). We review the diversity of these findings below.

Table 11. Significant Literature Findings using the Affective Flexibility Task

Switch Costs	Significant Literature Findings
1. Affective positive switch cost: $RT_{pos_{naff} \rightarrow pos\_aff} - RT_{pos\_aff \rightarrow pos\_aff}$, where poorer flexibility (i.e., higher RT switch costs) indicates greater difficulties in switching from the non-affective rule to the affective rule, in the presence of positive stimuli.	↑ SC → ↑ STAI (Twivy et al. 2021)
2. Affective negative switch cost: $RT_{neg\_naff \rightarrow neg\_aff} - RT_{neg\_aff \rightarrow neg\_aff}$, where poorer flexibility (i.e., higher RT switch costs) indicates greater difficulties in switching from the non-affective rule to the affective rule, in the presence of negative stimuli.	↑ SC → ↑ maladaptive coping (Grol & De Raedt 2021)
3. Non-affective positive switch cost: $RT_{posaff \rightarrow pos\_naff} - RT_{pos\_naff \rightarrow pos\_naff}$, where poorer flexibility (i.e., higher RT switch costs) indicates greater difficulties in switching from the affective rule to the non-affective rule, in the presence of positive stimuli.	↑ SC → ↓ rumination (Genet et al., 2013) ↑ SC → ↓ maladaptive coping (Grol & De Raedt, 2021)
4. Non-affective negative switch cost: $RT_{neg\_aff \rightarrow neg\_naff} - RT_{neg\_naff \rightarrow neg\_naff}$, where poorer flexibility (i.e., higher RT switch costs) indicates greater difficulties in switching from the affective rule to the non-affective rule, in the presence of negative stimuli.	↑ SC → ↑ rumination (Genet et al. 2013) ↑ SC → ↑ resting RMSSD (Grol & De Raedt, 2020) ↑ SC → ↓ reappraisal (Malooly et al. 2013) ↑ SC → ↓ STAI and worry (Twivy et al. 2021)

Note. Negaff = Negative image with affective rule; Negnaff = Negative picture with non-affective rule; *Posaff* = Positive image with affective rule; *Posnaff* = Positive image with non-affective rule; *RMSSD* = root mean square of successive differences between normal heartbeats; *RT* = Response Time; *SC* = Switch Costs; *STAI* = State-Trait Anxiety Inventory.

Switching from non-affective to affective processing of positive stimuli

First, with respect to processing positive information, Twivy and colleagues (2021) found that better flexibility (i.e., lower switch costs) when switching from the non-affective rule to the affective rule was associated with lower anxiety seven weeks later. In alignment with previous work reporting anxiety-related deficits in processing positive information (Taylor et al., 2011), difficulties engaging with positive stimuli was related to higher anxiety (i.e., poorer emotional outcomes).

Switching from non-affective to affective processing of negative stimuli

Second, for the processing of negative information, Grol and De Raedt (2021) found that better flexibility when switching from the non-affective to the affective rule in the presence of negative material predicted lower use of maladaptive coping in response of an acute stressor. Therefore, faster engagement with processing affecting aspects of negative material is associated with more adaptive emotion regulation strategies. To summarize, longer times engaging with the affective processing, regardless of the valence of the stimuli, is associated with worse emotion regulation outcomes.

Switching from affective to non-affective processing of positive stimuli

Third, the results for better flexibility (i.e., faster switching) when disengaging from affective to non-affective processing of positive information can be considered less adaptive. In a 6-day daily diary study, better flexibility from affective to non-affective aspects of positive stimuli predicted greater reports of rumination in response to the most unpleasant event of the day (Genet et al., 2013). Similarly, faster switching was also associated with greater spontaneous use of maladaptive cognitive emotional coping to an acute stressor, while there were no associations with stressor-induced negative affect or physiological stress (i.e., heart rate variability; Grol & De Raedt, 2021). In other terms, faster disengagement from the affective processing of positive stimuli is associated with less adaptive emotion regulation strategies, but not necessarily with emotional outcomes per se.

Switching from affective to non-affective processing of negative stimuli

Finally, better flexibility (*i.e.*, faster switching) when disengaging from affective to non-affective processing of negative images has been associated with contradictory outcomes (see Table 11). On the one hand, better flexibility has been related to better reappraisal effectiveness when instructed to downregulate sad affect induced with an emotional film (Malooly et al., 2013). Moreover, in the same 6-day diary study mentioned above, faster switching predicted lower reports of rumination to the most unpleasant event of the day (Genet et al., 2013). These two studies would suggest that better flexibility in disengaging from affective processing of negative information is related to more adaptive emotion regulation strategies.

On the other hand, the same index of flexibility predicted greater anxiety and worry seven weeks later in a prospective study of students (Twivy et al., 2021). In addition, better flexibility was also associated with lower resting levels of heart rate variability (HRV), indicative of poor autonomic flexibility, inadequate emotion regulation, and higher psychopathology (Grol & De Raedt, 2020). To reconcile these results with those reported for other switch costs (Table 11), it was hypothesized that anxiety may be associated with an initial heightened focus on negative or threatening information, followed by a tendency to actively avoid such stimuli(Cisler & Koster, 2010). Thus, better flexibility may, in some cases, lead to the avoidance of feared stimuli, notably through the rapid disengagement from the affective to the non-affective rule when treating negative information. In turn, this may maintain anxiety symptoms by obstructing the necessary processing of these stimuli. Indeed, such avoidance prevents the modification of threat associations through extinction learning (Borkovec, 1994). Overall, better disengagement from the affective aspects of negative stimuli appears to be associated with more adaptive affect regulation strategies but not necessarily with long-term positive emotional (both psychological and physiological) outcomes. To summarize, better flexibility switching from the non-affective to the affective rule is associated with more adaptive emotion regulation strategies and emotional outcomes (Table 11). By comparison, better flexibility when disengaging from negative stimuli may also have negative consequences over time. Thus, the role of affective flexibility for stress and resilience may depend on the rule and valence being processed. Further work in relation to emotional and behavioral responses to stress is required to identify the specific flexibility index involved.

6.2. Study 1: Affective Flexibility and Acute Laboratory Stress

The objective of the present study was to replicate Grol and De Raedt's (2021) laboratory study using the Maastricht Acute Stress Test (MAST; Smeets et al., 2012) by adding a control group (placebo-MAST). Beyond the cost-efficiency of the MAST, it also comprises components of both psychosocial and physical stress. Our goal was to explore how affective flexibility relates to changes in stress levels, as well as both positive and negative feelings, considering several emotional states using the Positive and Negative Affect Schedule (Watson et al., 1988). Additionally, we explored the associations between affective flexibility, appraisals and two common emotion regulation strategies applied spontaneously to the stressor: reappraisal and suppression (Gross, 2014).

Our hypotheses differed according to affect (stress and emotions; Hypothesis 1), appraisal (Hypothesis 2), and emotion regulation (Hypothesis 3). Given previous research on affective flexibility and emotions (see Table 11), better flexibility (*i.e.,* faster switching) from the affective to the non-affective rule when processing negative images, and worse flexibility towards the affective rule in presence of positive material should predict greater post-MAST stress compared to baseline (1a). Based on theoretical work, we expected similar findings for change in negative affect (1b) and the opposite effect for positive affect (1c). However, given the absence of such an effect reported for sadness/anger and feelings of happiness by Grol and De Raedt (2021), this hypothesis remained exploratory.

The second hypothesis, focused on appraisal, was also exploratory in nature given the absence of research on the subject. Given theoretical accounts of appraisals, however, we expected better flexibility to be associated with more adaptive appraisals of the situation. More specifically, better flexibility from the affective rule to the non-affective rule in the presence of negative stimuli should be associated with lower valence appraisals and higher control.

Finally, the third hypothesis focused on reappraisal and suppression. We expected to replicate previous work conducted in other contexts, in that better flexibility from processing affective to non-affective aspects of negative materials should be associated with higher use of reappraisal (Malooly et al., 2013; Hypothesis 3a). In contrast, higher use of suppression – often perceived as "maladaptive" – during the stressor should be associated with (a) poorer flexibility switching towards the affective rule in presence of negative stimuli and (b) better flexibility from affective to non-affective aspects of *positive* stimuli (Genet et al., 2013; Grol & De Raedt, 2021).

Methods

Participants

The data used for this study was based on a sub-sample of a preregistered study that can be consulted on the Open Science Framework (OSF) platform (https://osf.io/59cqe) and received approval from the UCLouvain Ethics Commission of the Institute for Research in the Psychological Sciences on 06/10/2021 (reference: Project 2021-43). Participants were recruited through social media announcements, such as Facebook. To be eligible, individuals had to be between 18 and 35 years of age, declared that they were in good physical and mental health, and proficient in French. A predetermined sample size of 131 was calculated using G*Power (3.1.9.7) to meet required statistical standards for the original aims and hypotheses. A total of 154 participants were recruited for this study. Ten participants did not complete Time 2 of the study, 14 individuals presented problems with the online cognitive task: thus, these individuals were excluded from analyses.

Participants were randomly assigned to either the MAST or placebo-MAST experimental groups, with 87 (44 women, 43 men) and 43 (27 females, 16 men) participants in each, respectively. The decision to recruit a greater number of participants in the experimental group was rooted in the objectives of Studies 2 and 3 of the initial preregistered projects (see https://osf.io/59cqe). Hence, the results for this study focused on the individuals in the MAST condition, only. A G*Power analysis was conducted to estimate the necessary sample size. A total of 85 participants was deemed necessary to detect a medium effect size ($f2$ = .15), alpha = .05 and 80% power, for a multiple regression model with four predictors (all four affective flexibility costs) and (at most) four covariates (baseline – *i.e.*, stress or affect –, gender, age, and chronic stress measured by the Perceived Stress Scale (Cohen et al., 1994) if necessary.

There was a significant difference between the two groups in terms of chronic stress: the experimental group had lower chronic stress scores (*M* = 19.33, *SD* = 6.61), compared to the control group (*M* = 22.60, *SD* = 6.82; $t(124) = 6.67$, p =.011). Consequently, chronic stress was controlled for in later regression models. There were no other significant differences in sociodemographic characteristics or affective flexibility switch costs, suggesting that random assignment between the two groups was well conducted.

Design and Procedure

The dataset used in this study stems from a bigger project on stress, alexithymia, and emotion regulation. The full experimental procedure and design were preregistered prospectively, before data was collected. They are available in the pre-registration of the project (https://osf.io/59cqe) and part of this procedure was also described elsewhere (Grimm et al., *in prep*). In this section, we describe the relevant measures in terms of the current study aims and hypotheses, only. The current data was collected in two steps. In the initial test phase conducted at home, participants engaged in an online questionnaire session via Qualtrics (Provo, UT), including sociodemographic information, chronic stress and alexithymia measures. Participants were then redirected to an online affective flexibility task (Malooly et al., 2013) hosted on Inquisit Web, which they completed remotely from their personal computers. Following the task, participants rated their level of attention during the task, the relative effort they exerted (*i.e.*, investment into the task), as well as whether or not they believed their data should be retained for the analyses.

Following a 48-hour interval, participants arrived at the laboratory. Upon arrival, they completed a single-item stress assessment and the Positive and Negative Affect Scale. Subsequently, participants were randomly assigned to undergo either the Maastricht Acute Stress Test (MAST; Smeets et al., 2012) or the placebo condition (Placebo-MAST) that were administered by a trained master's research assistant. Previous research has consistently demonstrated significant physiological responses to the MAST, such as increased cortisol levels, heart rate, blood pressure, and subjective stress and anxiety during the MAST compared to participants in the placebo equivalent (Shilton et al., 2017; Smeets et al., 2012). Following the MAST, participants completed a last set of questionnaires assessing several variables including stress levels, emotional states, task appraisal, and employed emotional regulation strategies (see Figure 19).

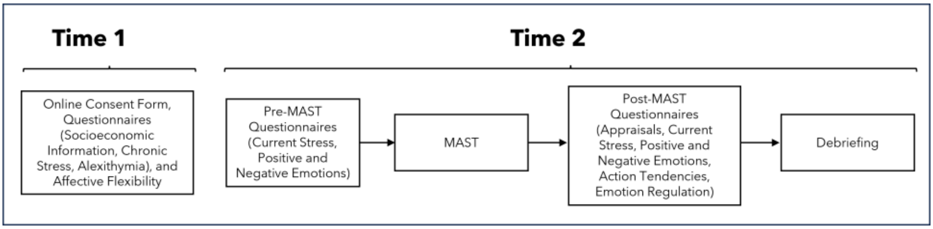

Figure 19. Overview of Study Procedure (Modified from Grimm et al., 2024)

Measures

Affective Flexibility

Affective flexibility was assessed using a task-switching task adapted from Malooly and colleagues (Genet et al., 2013; Malooly et al., 2013) and other research teams (Grol & De Raedt, 2020; Twivy et al., 2021) administered on Inquisit Web (Build 6.1.2.). Participants were asked to categorize emotional images based on two distinct criteria: whether they were positive or negative (affective rule), and whether they depicted one or fewer individuals versus two or more (non-affective rule). All images were sourced from the International Affective Picture System (IAPS, Lang et al., 2008). The selected images were categorized into groups ensuring balanced representation across valence and the number of people depicted, as provided and applied by Grol and De Raedt (2020). Forty different images were used for each of the four categories: negative with two or more people, negative with one or fewer people, positive with two or more people, and positive with one or fewer people (a total of 160 images; mean valence ratings can be found in Twivy et al., 2021). Negative images included both threat and non-threat (sadness/loss-related) stimuli. Twenty additional images were implemented in the practice blocks to avoid habituation effects from pictures used across both practice and test blocks.

Each trial began with a brief presentation (250ms) of a black screen, followed by a fixation cross (250ms). An image was presented in the center of the screen, alongside task cues. Participants were asked to respond as quickly and accurately as possible to each new image, using the B and N keys according to task rule. The participant was shown the image and cues until they reacted, or up to 5000 ms (response limit). There were eight different task conditions: these varied in terms of the mapping of keys (B vs. N) to affective and non-affective rules, as well as the background color of the images (grey vs. white). This allowed for the counterbalancing of different combinations of cue to response key mappings and task rule to background color mappings. All participants completed two 10-trial practice blocks, where they separately trained for the affective and non-affective categorization rules, respectively. The test phase consisted of two blocks of 160 trials, which were presented in a predetermined pseudorandom order (Malooly et al., 2013).

Questionnaires

Chronic Stress. The Perceived Stress Scale (PSS-10, Bellinghausen et al., 2009; Cohen et al., 1994) was applied to measure chronic stress over the past month. Participants evaluated their experiences using a 10-item scale ranging from 0 (indicating never) to 4 (indicating very often), with four items being reverse-scored. The total score was derived by summing all items and demonstrated high internal reliability in the current study ($\alpha = .85$, $\omega = .86$).

Stress Item. Based on previous studies (Becker & Rohleder, 2019; Lesage et al., 2012; Luettgau et al., 2018; Paszkiel et al., 2020), pre- and post-stressor perceived stress was assessed using a visual analog scale that ranged from 0 (not stressed at all) to 10 (extremely stressed). In our previous study (Grimm & Agrigoroaei, 2024), this item correlated significantly with general anxiety levels, at baseline [$r(83)=0.62$, $p<.001$], MAST [$r(83)=0.65$, $p<.001$], and post-MAST [$r(83)=0.57$, $p<.001$].

Positive and Negative Affect. Before and after the MAST, the Positive and Negative Affect Schedule (PANAS; Original version: Watson et al., 1988; French version: Gaudreau et al., 2012) was administered to evaluate participant's *current* mood states. This scale comprises 20 items rated on a five-point self-report scale (1 = not at all to 5 = completely). Separate total scores for positive mood (sum of 10 items, including interest and pride) and negative mood (sum of 10 items, including guilt or fear). Both negative and positive mood states demonstrated high internal reliability both before ($\alpha = .83$, $\omega = .84$ and $\alpha = .78$, $\omega = .80$, respectively) and after ($\alpha = .83$, $\omega = .83$ and $\alpha = .82$, $\omega = .83$, respectively) the stress induction.

Appraisal. Following the stress induction, several dimensions of appraisal were assessed using a self-reported questionnaire adapted from prior studies (Grandjean & Scherer, 2019; Luminet et al., 2004; Scherer & Moors, 2019). This questionnaire originally comprised 10 items, each with four sub-items presented to participants on a scale from -3 to 3. For analytical purposes, these were coded 0 to 7. Valence was calculated as the average on the three following items: "This task was, for me, (a) pleasant – unpleasant, (b) desired – undesired, (c) a success – a failure", with higher scores representing a more negative valence. Control was calculated as the average on the following items: "I felt (a) strong – weak, (b) powerful – helpless, (c) "master" of the events – overwhelmed by the events", with higher scores presenting lower control. Internal reliability was deemed satisfactory for the three items representing each retained dimension of appraisal: valence ($\alpha = .66$, $\omega = .67$) and control ($\alpha = .89$, $\omega = .90$).

Emotion Regulation. The Emotion Regulation Questionnaire (ERQ; Gross & John, 2003, French version: Christophe et al., 2009) was administered in this study. The scale consists of 10 items. For each item, participants rate their level of agreement on a scale from 1 (not at all) to 5 (strongly agree). Of the items, six assessed cognitive reappraisal (e.g., "I changed the way I look at the task so that I feel fewer negative emotions") and four assessed expressive repression (e.g., "I kept my emotions to myself"). The internal consistency of cognitive reappraisal was deemed satisfactory ($\alpha = .68$, $\omega = .69$). However, due to an encoding error, one item was omitted from the experiment for a portion of the sample, resulting in the computation of total scores based on only three items for all participants. The internal consistency score for expressive suppression with three items fell below an acceptable reliability threshold ($\alpha = .42$, $\omega = .58$). Upon discovering and reintegrating the missing item in Qualtrics, we were able to calculate the original suppression subscale (i.e., with four items) for the last participants ($N = 47$; $\alpha = .65$, $\omega = .70$). Given the better consistency of the latter score, we report the regression results for this outcome but acknowledge the lower statistical power and advise caution in their interpretation.

Data Analysis

Transparency and Openness

Switch cost cleaning and calculations were conducted in Microsoft Excel, while data analysis was conducted with RStudio (2023.06.1). We report how we determined our sample sizes, all data exclusions, all manipulations, and all measures in both studies.

Switch Cost Calculations

Response time (RT) switch costs were calculated according to Malooly and colleagues' (2013) procedure. Only correct trials and trials preceded by a correct response were included in the computation. This methodological decision aligns with prior studies, as trials following incorrect responses introduce uncertainty regarding whether the subsequent trial represents a repetition or a switch from the participant's perspective. Additionally, accounting for post-error slowing effects could bias switch cost calculations. This procedure resulted in an average of 16.13% of trials deleted. To reduce the impact of outliers (Genet et al., 2013; Malooly et al., 2013), RTs that were 2.5 standard deviations above and below an individual's mean RT for a specific trial type were substituted with upper and lower cut-off values. The average trimmed RT for each trial type was calculated and used for final switch costs calculations.

Overall switch costs, indicative of shifting efficiency between task rules irrespective of valence, were computed by subtracting average trimmed reaction times on repetition trials from that on switch trials. A paired-t test confirmed that trials on which participants were asked to switch rules ($M = 1457.66$, $SD = 300.83$) were significantly longer compared to repetition trials ($M = 1313.52$, $SD = 257.01$; $t(83)=13.91$, $p < .001$). Thus, a further four types of switch costs were computed separately for different conditions, reflecting shifts in affective and non-affective processing of negative and positive material (see Table 16). For example, non-affective negative switch costs are calculated by subtracting the average RTs on trials where participants repeated the non-affective task rule in the context of negative images from the average RT on trials where participants switched from the affective rule to the non-affective rule in the context of negative images. Higher switch costs therefore represent longer times switching from the affective rule to the non-affective rule in presence of negative stimuli.

Pairwise comparisons confirmed significant differences across all switch costs for both studies[1]. In ascending order of switch cost durations, we observed shorter times (1) disengaging from the affective rule with negative information, followed by (2) engaging with the affective rule with positive information, (3) disengaging from the affective rule

[1] The only exception was in Study 1, where positive non-affective switch costs and negative affective switch costs were *not* significantly different from one another ($p = .105$).

with positive information, and (4) engaging with the affective rule in the presence of negative material (see Table 12).

Stress Induction Verification

The efficacy of the stress induction was verified using repeated-measures ANOVA with group (MAST vs. placebo-MAST) as a between-subject factor and time (pre- and post-MAST levels) as a within-subject factor, as well as their interaction. Pairwise comparisons with Bonferroni correction were conducted to determine the significance of the effect (Full statistical analyses descriptions are available as Supplementary Materials).

Regression Models

As we did not anticipate the observation of associations with stress within the placebo group, all analyses were exclusively conducted on the experimental group. A total of seven regression models were conducted, with stress, negative affect, positive affect, valence perceptions, control perceptions, reappraisal, and suppression as outcomes, respectively. For the first three models, respective baseline values were included as covariates in the model to predict stressor-induced changes in the variable (e.g., the models controlled for pre-MAST stress when predicting post-MAST stress). Additionally, all four switch costs were included as predictors in the models. Relevant covariates were verified using correlations prior to the regression models. Significant associations between age and chronic stress were observed; thus, they were included as covariates in the regression models. The residuals for self-reported stress and negative affect were not normally distributed, so we applied log transformations to both outcomes to meet model assumptions. With respect to appraisals, the regression model predicting valence perceptions showed problems with heteroscedasticity. Log-transformation of the outcome did not solve the problem, though removing residual outliers did. Data for the regression model for control violated the assumption of heteroscedasticity and non-normality of residuals. Log-transformation and removal of outliers did not solve the issue, thus heteroscedasticity-robust standard errors were calculated.

Finally, we conducted separate mediational models (using the PROCESS function for R; Hayes, 2022) with valence perception, control, reappraisal, and suppression as mediators between relevant affective flexibility indices and stress, negative affect, or positive affect. These were conducted if we observed (1) significant associations between the switch costs and the mediator, and (2) significant associations between the mediator and stress, negative affect, or positive affect. Mediational model 1, with 95% confidence intervals and 5000 bootstrap samples, had suppression as the mediating variable. The other switch costs, age, and chronic stress were covariates.

Results

Sample Characteristics

Three participants presented a task accuracy below 50% in at least one of the testing blocks were removed. This resulted in a final sample of 84 individuals in the experimental group, aged between 18 and 33, with females constituting 51.19 % and years of education ranging from 12 to 24 years (see Table 12 for full participant characteristics).

Table 12. Participant Characteristics and Descriptive Statistics for Study 1

	Study 1 (*N* = 84)	
	Mean	*S.D.*
Participant Characteristics		
Age (years)	22.44	3.24
Gender (% female)	51.19%	
Years of Education (years)	15.69	2.52
Affective Flexibility Tasks		
Non-Affective Negative Switch Costs (ms)	55.84	217.20
Non-Affective Positive Switch Costs (ms)	189.17	172.77
Affective Negative Switch Costs (ms)	240.44	287.54
Affective Positive Switch Costs (ms)	133.72	182.62
Stress-related Outcomes		
Examination stress		
Chronic Stress	19.33	6.61
Pre-MAST PANAS-Stress	2.52	2.09
Post-MAST PANAS-Stress	3.56	2.47
Pre-MAST PANAS-NA	14.30	4.37
Post-MAST PANAS-NA	19.10	7.05
Pre-MAST PANAS-PA	31.61	5.32
Post-MAST PANAS-PA	27.83	6.50
Mediators		
Valence	5.27	1.14
Control	5.11	1.39
Reappraisal	17.11	4.90
Suppression	7.35	2.34

Note. MAST = Maastricht Acute Stress Test; *M* = Mean; *PANAS* = Positive and Negative Affect Schedule; *SD* = Standard deviation.

Affect Induction Verification

For stress, there was a significant interaction effect between group and time [$F(1,124) = 35.85$, $p<.001$]. More specifically, there was a significant increase in stress in the experimental group between pre- ($M = 2.52$, $SD = 2.08$) and post-MAST ($M = 3.56$, $SD=2.47$; $p < .001$). In contrast, there was a significant decrease in stress in the placebo group between pre- ($M = 3.31$, $SD = 2.27$) and post-MAST ($M=2.36$, $SD = 2.12$, $p<.001$; see Figure 20).

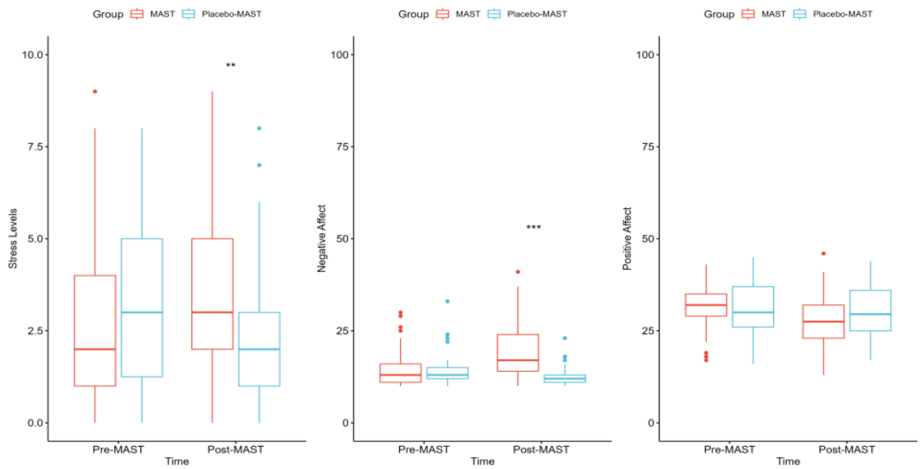

Figure 20. Group Differences in Changes in Stress Levels and Affect (Positive and Negative) before and after MAST Administration

Note. Asterisks indicate significant differences between groups: ** p <.01, *** p<.005.

For negative affect, there was a significant effect of group [$F(1,124) = 13.92$, p <.001], time [$F(1,124) = 6.88$, p =.010], and interaction between time and group [$F(1,124) = 48.20$, p <.001]. While there were no significant differences in mean negative affect at baseline between the two groups, there was a significant difference at post-MAST (p <.001). Participants in the experimental group showed a significant increase in negative affect between baseline (M = 14.30, SD = 4.36) and post-MAST (M = 19.10, SD = 7.05, p <.001). In contrast, participants in the control group experienced a decrease in negative affect from baseline (M = 14.57, SD = 4.56) to post-MAST (M = 12.40, SD = 2.79, p <.001; see Figure 20).

Correlations

All correlations between Study 1 variables are presented in Figure S1 in the Supplementary Materials. Non-affective positive switch costs were significantly and negatively associated with age [$r(82)$ = -0.24, p = .029] and years of education [$r(82)$ = -0.27, p = .012], and positively with post-stressor positive affect [$r(82)$ = 0.24, p = .031]. Suppression was significantly associated with post-MAST negative affect [r(45) = .31, p = .035]. Chronic stress was significantly and positively correlated with pre- [$r(82)$ = 0.22 , p = .042] and post-MAST stress [$r(82)$ =0.41, p<.001], as well as with pre- [$r(82)$ = 0.23, p = .033]. and post-MAST negative affect [$r(82)$ = 0.30, p = .006]. Thus, we included age and chronic stress as covariates in all regression models[2]. None of the switch costs correlated significantly with the mediators.

Regression Models

Reactivity in Stress and Affect

The multiple regression model for post-MAST stress revealed a significant positive effect of pre-MAST stress (see Table 13 for the full regression model). However, the assumption of normality of residuals was not respected. We applied a log transformation of the outcome, which removed this effect. With respect to negative affect, only baseline negative affect emerged as a significant predictor of post-MAST negative affect (see Table S1). Similarly, when accounting for all flexibility variables, only baseline positive affect was a positive predictor of post-MAST positive affect (see Table S1).

Table 13. Regression Models for Affective Flexibility Predicting Post-MAST Stress Levels and Suppression during the MAST

	Post-MAST Stress			**Log-transformed Post-MAST Stress**			**Suppression**		
Predictors	*Std. Beta*	*Std. CI*	*p*	*Std. Beta*	*Std. CI*	*p*	*Std. Beta*	*Std. CI*	*p*
Pre-MAST Stress	**0.57**	**0.40 – 0.74**	**<0.001**	**0.51**	**0.33 – 0.68**	**<0.001**			
Non-Affective Positive SC	-0.09	-0.27 – 0.08	0.292	-0.11	-0.29 – 0.08	0.247	0.09	-0.25 – 0.43	0.595
Non-Affective Negative SC	0.05	-0.12 – 0.21	0.566	0.04	-0.13 – 0.21	0.648	0.13	-0.17 – 0.44	0.381
Affective Positive SC	0.14	-0.02 – 0.31	0.094	0.14	-0.03 – 0.31	0.115	-0.13	-0.44 – 0.17	0.382
Affective Negative SC	**0.17**	**0.01 – 0.34**	**0.041**	**0.14**	**-0.04 – 0.31**	**0.119**	**-0.34**	**-0.65 – -0.02**	**0.039**
Age	0.06	-0.10 – 0.23	0.447	0.03	-0.14 – 0.21	0.700	0.16	-0.15 – 0.46	0.304
Chronic Stress	**0.24**	**0.08 – 0.41**	**0.004**	**0.30**	**0.13 – 0.47**	**0.001**	0.23	-0.08 – 0.53	0.595
Observations	84			84			47		
R^2 / R^2 adjusted	0.530 / 0.487			0.490 / 0.443			0.169 / 0.045		

Note. *CI* = Confidence Intervals; *SC* = Switch Cost; *Std* = Standardized.

[2] Age and years of education correlated strongly and positively [$r(82) = 0.85$, $p < .001$], thus we chose to retain the former only to avoid redundancy.

Mediators

Appraisal. None of the flexibility switch costs were significant predictors of either valence perception or control (see Table S2).

Emotion Regulation. None of the flexibility indices predicted reappraisal (see Table S3). However, shorter time to switch towards the affective rule in presence of negative material significantly predicted more suppression during the MAST (see Table 13). The mediation model for affective negative switch cost and suppression, however, failed to reveal a significant direct, indirect, or total effect. While path a (flexibility on suppression) was significant (β = -0.34, p = .033), path b (suppression on post-MAST negative affect) was not (β = .27, p = .068). Hence, there is no confirmed mediation effect of suppression, though the sample size may explain this finding.

Discussion

The aim of this first study was to replicate Grol and De Raedt's (2021) laboratory experiment using the MAST (Smeets et al., 2012) and different measures of affect, appraisal, and regulation strategies. None of our predictions were supported in this study. However, there were two significant effects, namely for self-reported stress and for the use of suppression. Both related to flexibility in switching from the non-affective to the affective rule when processing *negative* information.

First, we found that better flexibility was associated with lower subjective stress reported immediately after the stressor. While this was not a hypothesized outcome – notably because this effect had not been reported in past studies (see Table 11) – it still aligns with our original hypothesis. While we initially expected that quicker disengagement from processing affective negative information would lead to greater self-reported stress, our findings suggest the opposite: slower engagement with the affective processing of negative stimuli was related to higher stress levels.

Major cognitive theories regarding attentional threat biases in anxiety propose a bottom-up mechanism towards threatening stimuli. Previous work has established that attention biases are often directed toward threat- or danger-related cues, resulting in rapid detection and processing of threatening stimuli (Cisler & Koster, 2010). This adaptive mechanism helps individuals to respond promptly to potential dangers but can also protect against psychological disorders (for a review, see Wieser & Keil, 2020). Additionally, vigilance-avoidance models suggest that conscious attentional processes play a role in avoiding negative material to alleviate distress or actual danger (Eysenck et al., 2007). In line with these theoretical frameworks, studies have found that individuals with high levels of experiential avoidance tend to experience more unpleasant emotions in response to emotion-eliciting films (Sloan, 2004). Thus, our findings suggest that slower disengagement from non-affective aspects of affective stimuli when processing negative information may reflect experiential avoidance during stressful situations, leading to sustained feelings of stress following the stressor.

Second, we also found that better flexibility in switching from the processing non-affective to the affective rule with negative material was related to significantly more use of suppression during the stressor. Although counterintuitive, individuals who could effectively direct their attention towards processing the affective rule may have been more inclined to suppress the expression of their emotions as a way to cope with the situation. As we had expected the opposite effect, researchers must carefully consider the context(s) in which flexibility and suppression are studied. Although we did not ask participants *why* they were spontaneously using this strategy, it is important to remember that they believed they were being filmed and their emotions analyzed. Thus, suppressing their emotions in response to the stressor may have served an adaptive purpose in this context.

Our results suggest a non-linear association between flexibility and functionality. Better flexibility is not always linked to traditionally "adaptive" outcomes: while greater flexibility in processing negative information was associated with lower self-reported stress, it also correlated with higher use of suppression. Suppression is often viewed as maladaptive compared to reappraisal due to its negative effects on emotional experience, stress, memory, social functioning, and general well-being (Cutuli, 2014; Gross, 2002). However, the mediating effect of suppression was not significant: although poorer flexibility predicted lower use of suppression during the stressor, suppression had no subsequent impact on subjective stress. Recent approaches to affect regulation emphasize that strategies are context-dependent rather than inherently good or bad (Aldao et al., 2015). In this case, flexibility may have influenced affect regulation choices without necessarily impacting subsequent emotions and stress. Future studies should explore how strategy choices and their effectiveness vary depending on specific stressors, motivations, and goals.

Despite these interesting findings, it is important to note that a large proportion of our predicted hypotheses were not supported by the data. Flexibility when engaging with the affective processing of negative information was the only significant switch cost across all regression analyses, perhaps suggesting it holds a central role in the context of acute stress. On the contrary, there was an absence of effect of affective flexibility in predicting either stressor-induced changes in positive or negative affect (in line with Grol & De Raedt, 2021), appraisals of valence and control, or reappraisal. We discuss the limitations observed, including the administered task, in the general discussion. First, we aimed to investigate whether these findings could be generalized to stress experienced in anticipation of a common, real-life stressor: university examinations.

6.3. Study 2: Affective Flexibility and Academic Stress

Aims and Hypotheses

Anticipatory stress refers to the physiological and subjective responses upon being informed about an impending stressful event, before its actual occurrence (Engert et al., 2013). The anticipation of a situation one perceives as threatening and stressful can elicit reactions akin to those experienced when directly confronted with the stressor, including increased negative mood, cardiovascular activity, and cortisol release (Mikolajczak et al., 2008; Waugh et al., 2010). An important illustration of such phenomenon is the stress experienced by most university students ahead of the examination period.

The role of this second study was to examine the extent to which affective flexibility acted as a protective factor of examination-related stress. To replicate Study 1's findings, we expected that poorer flexibility switching from the non-affective rule to the affective rule when processing negative materials should predict greater stress in anticipation of the upcoming examination session (Hypothesis 1). Building on our literature review (see Table 11), we also maintained Study 1's hypotheses, expecting that (a) better flexibility to the non-affective rule in presence of negative material and (b) worse flexibility switching to the affective rule when processing positive information should both be related to greater anticipatory stress ahead of the examinations.

Furthermore, the study also investigated the associations between affective flexibility and both appraisals and affect regulation strategies implemented to deal with stress in light of the upcoming examination period. Given the absence of previous findings regarding appraisal (e.g., Study 1; Grimm & Agrigoroaei, 2023), we did not expect to find significant associations with affective flexibility (Hypothesis 2). However, should an association emerge, we expected better flexibility disengaging from the affective rule when processing negative information to predict more control and less threat.

With respect to coping, we expected different switch costs to be associated with "adaptive" and "maladaptive" coping. Based on findings with reappraisal (Malooly et al., 2013), we expected better flexibility when switching from the affective to the non-affective rule when processing negative material to be associated with greater adaptive coping. For maladaptive coping, we expected to replicate Grol and De Raedt (2021)'s findings, where (a) better flexibility switching from affective to non-affective aspects of positive stimuli, while (b) poorer flexibility shifting from the non-affective to the affective processing of negative stimuli should predict greater use of maladaptive coping in anticipation of the examinations (Hypothesis 3; Grol & De Raedt, 2021). However, the results from Study 1 reported the opposite effect. Therefore, we approached this hypothesis in a more exploratory manner.

Finally, we expected to replicate the findings reported by Twivy and colleagues (2021), in that better flexibility switching from affective to non-affective aspects of *negative* materials should predict greater worry about the upcoming stressor two months later (Hypothesis 4). We will explore the mediating role of appraisal, coping, and worry, should they emerge as significantly correlated with any of the affective flexibility switch costs.

Methods

Participants

Participants were recruited from a second-year undergraduate methodological psychology course at the UCLouvain Faculty of Psychology and Educational Sciences to participate in exchange of course credit. Inclusion criteria comprised being over the age of 18, being an undergraduate student, and speaking French as a native language (or having acquired it before the age of 10). G*Power software (3.1.9.7; Faul et al., 2007) was used to estimate a target sample size of 127 individuals to be recruited for this study, using an estimated power of 0.80 and an estimated mean effect size of $f^2 = 0.15$, to perform multiple regression analyses with fifteen predictors (most complete model with age, gender, and chronic stress as covariates). As we expected at 10% drop-out rate at post-test, we recruited 142 individuals.

Design and Procedure

The study received ethical approval by the Saint-Luc-UCLouvain Biomedical Ethics Committee, and it was implemented online. The timeline of the study was established based on the January session of academic exams and included two times of assessment. At Time 1 (26.46 to 51.58 days prior to their first exam, $M = 35.68$, $SD = 4.57$; see Figure 21 for an overview), participants completed, at home, the consent form and a series of questionnaires inquiring about sociodemographic information and chronic stress on Qualtrics (Provo, UT). After completing these questionnaires, they were redirected to the Inquisit Web platform and were administered three cognitive tasks online, on their personal computer. At Time 2 (approximately one week before their examinations), they received a link to the online questionnaires evaluating anticipated stress, appraisals, coping strategies, and worry ahead of the examinations.

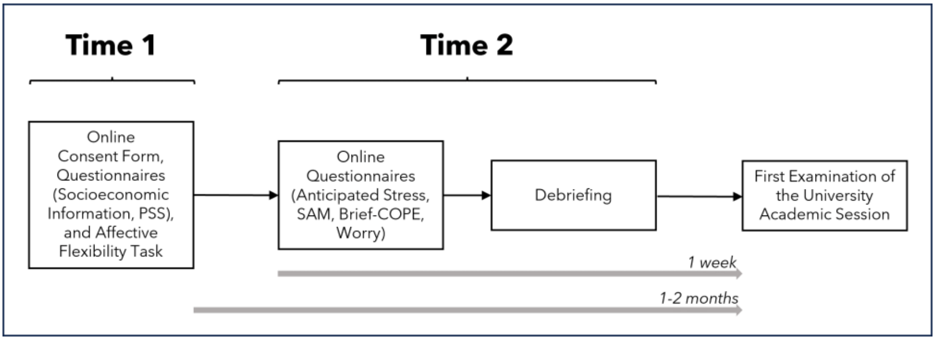

Figure 21. Overview of Study 2 Procedure

Note. PSS = Perceived Stress Scale; *SAM* = Stress Appraisal Measure.

Measures

Questionnaires

Sociodemographic Variables. Participants provided information regarding gender, age, and years of education.

Chronic Stress. The Perceived Stress Scale (PSS) was used to assess the amount of stress experienced during the past month (French version: Bellinghausen et al., 2009). The total score was calculated by summing all items, where higher scores indicated higher levels of chronic stress. The scale presented high internal consistency, with Cronbach's α of .83 and ω of.83.

Anticipatory Examination Stress. Anticipatory stress was operationalized at Time 2 as the mean of five items graded on a visual analogue scale from 0 to 10 in anticipation of the upcoming exam session in January (based on Center for Studies on Human Stress, 2019): (a) perceived stress concerning the exam session, on a scale from complete absence of stress to the most extreme level of stress ever experienced (Lesage et al., 2012); (b) perceived level of control over the exam session, on a scale ranging from complete absence of control to the highest level of control (reversed item); (c) capacities, evaluating the extent to which participants felt their skills were being challenged, in the extent that aspects of their personality or ability to succeed in the exam session were being tested, on a scale from complete absence to the highest level of being tested; (d) novelty inquiring whether participants regularly encountered new challenges in light of the upcoming exams, rated on a scale from complete absence of novelty to the highest level of novelty; and (e) degree of unpredictability participants perceived ahead of the exam session, on a scale from complete absence of unpredictability to the highest level of unpredictability. Internal consistency for this set if item was adequate ($\alpha = 0.67$, $\omega = 0.68$).

Appraisal. At Time 2, the primary and secondary appraisals of the upcoming examination session was assessed using the Stress Appraisal Measure (Grimm et al., 2024;

Peacock & Wong, 1990). Participants were instructed to consider the upcoming examination session and assess the relevance of 28 items to their situation. They used a scale ranging from 1 (not at all) to 5 (extremely). The measures of primary appraisals include centrality (i.e., whether "the encounter with the environment is relevant to his or her well-being"; Folkman et al., 1986, $\alpha = 0.75$, $\omega = 0.76$) and challenge/threat (higher scores indicate higher likelihood of perceiving the event as challenging; $\alpha = .65$, $\omega = .69$). Measures of secondary appraisals include perceptions of control by oneself ($\alpha = 0.87$, $\omega = 0.87$) or by others ($\alpha = 0.88$, $\omega = 0.88$), or uncontrollability by anyone ($\alpha = 0.76$, $\omega = 0.77$).

Coping. The BRIEF-COPE (French version; Muller & Spitz, 2003) situational version was modified to evaluate the coping mechanisms implemented prior to the stressor. Participants indicated the degree to which they employed 28 coping strategies in preparation for the examination period. They used a Likert scale ranging from 1 (I haven't been doing this at all) to 4 (I have been doing this a lot). Although the original scale forms fourteen coping categories, Meyer (2001)'s methodology was applied to calculate two coping behavior indices: adaptive and maladaptive behaviors. The average score for active coping, planning, instrumental support, emotional support, emotional expression, positive reappraisal, and acceptance was found to be indicative of adaptive coping ($\alpha = .75$, $\omega = .78$). The average of denial, blame, distraction, substance use, and behavioral disengagement subscales represented maladaptive coping ($\alpha = .65$, $\omega = .67$)[3].

Worry. The Penn State Worry Questionnaire (PSWQ; French version: Gosselin et al., 2001) was used to measure worry. The questionnaire consisted of 16 items, with each item is rated on a Likert-type scale spanning from 1 (not at all typical of me) to 5 (very typical of me). Participants were instructed to indicate the degree to which each statement aligns with their current experiences and thoughts The total score was the sum of all items ($\alpha = .92$, $\omega = .92$).

Affective Flexibility

The affective flexibility task administered in Study 2 was identical to that presented in Study 1. A paired-t test confirmed that trials on which participants were asked to switch rules were significantly longer (M = 1429.63, SD = 226.50) than repetition trials [M = 1276.86, SD =195.05; $t(122) = 18.43$, $p<.001$]; thus, the four switch costs were calculated. An average of 15.42% of trials were deleted for calculating the switch costs in this study.

Data Analysis

All analyses were conducted in RStudio 2023.06.1 (Build 524). To ensure higher quality data collection, we included a response validation item in the Time 1 and Time 2 questionnaires, instructing participants to "select response 2". Participants failing to select

[3] Removing the items relating for which the loading were the lowest on the distraction subscale did not lead to any significant change in the correlations or regression models. Therefore, all items were maintained in the subscale calculation.

the expected response were removed from further analysis. To reduce the impact of extreme outliers, they were defined as data that was more than three times the interquartile range above or below the first or third quartile, respectively (Soveri et al., 2018). Five individuals represented extreme outliers on at least one of the switch costs.

Prior to any regression analysis, we conducted correlations between the affective flexibility switch costs with anticipated examination stress and all possible mediating variables (primary and secondary appraisals, adaptive and maladaptive coping, and worry). Correlations with sociodemographic variables were also conducted to determine the relevant variables required to be controlled for in the models. Examining the variable boxplots revealed that age, years of education, uncontrollability were non-normally distributed. As a result, we initially ran nonparametric Spearman correlations for these, while all other correlations were parametric (Bravais Pearson's r). However, given that the results (strength and significance) from the correlational models do not change, we report the latter only.

All affective flexibility switch costs were included as predictors in the regression models, along with relevant sociodemographic variables that correlated significantly with the predictors and/or outcomes. A separate regression model was conducted per outcome, resulting in a total of nine models. All regression assumptions were verified, with either (a) log-transformation of the outcome or estimation of heteroscedasticity-robust standard errors if homogeneity of variance or normality of the residuals was not respected, and (b) deletion of residual outliers and re-running of the model without these if extreme outliers in the standardized residuals were observed. The assumption of heteroscedasticity was not respected for anticipated examination stress, and transforming the outcome did not solve the problem. Thus, heteroscedasticity-robust standard errors were calculated on the initial model. The results remain significant; we display the original model. Finally, we conducted separate mediational models (using the *PROCESS* function for R; Hayes, 2022) with appraisals, coping strategies, and worry as mediators between relevant affective flexibility switch costs and anticipatory examination stress. Similarly to Study 1, these were conducted if we observed (1) significant associations between the switch costs and the mediator, *and* (2) significant associations between the mediator and anticipatory stress. Mediational models 1 and 2, with 95% confidence intervals and 5000 bootstrap samples, had perceptions of uncontrollability and maladaptive coping as the mediating variable, respectively. For the two models, the other switch costs, gender, and chronic stress were included as covariates.

Results

Descriptive Statistics

Individuals were removed from the initial sample (N = 142) due to problems or missing data on the affective flexibility task (N = 9), missing data on the questionnaires at Time 2 (N = 3), failing the bogus item in the Time 2 questionnaires (N = 2), or representing an extreme outlier on one of the affective flexibility switch costs ($N = 5$). The final sample consisted of 123 individuals aged 19 to 39, with 82.93% being female and having 12 to 19 years of education (see Table 14).

Gender was significantly associated with chronic stress [$r(121) = 0.32$, $p = .005$; see Figure S2] and worry [$r(121) = -0.24$, $p = .004$], while chronic stress was significantly associated with higher maladaptive coping [$r(121) = .28$, $p = .002$], worry [$r(121) = 0.56$, $p < .001$], centrality [$r(121) = 0.27$, $p = .020$], challenge/threat [$r(121) = -0.29$, $p = .001$], controllable by oneself [$r(121) = -0.40$, $p < .001$], controllable by others [$r(121) = -0.22$, $p = .014$], and anticipatory stress [$r(121) = 0.42$, $p < .001$]. Thus, gender and chronic stress were included in all regression models.

Table 14. Participant Characteristics and Descriptive Statistics for Study 2

	Study 2 (N = 123)	
	Mean	*S.D.*
Participant Characteristics		
Age (years)	20.70	2.36
Gender (% female)	82.93%	
Years of Education (years)	13.93	1.78
Affective Flexibility Tasks		
Non-Affective Negative Switch Costs (ms)	69.86	196.32
Non-Affective Positive Switch Costs (ms)	190.19	169.46
Affective Negative Switch Costs (ms)	259.41	198.64
Affective Positive Switch Costs (ms)	134.40	195.03
Stress-related Outcomes		
Examination stress	5.09	1.43
Chronic Stress	19.41	6.16
Mediators		
Challenge/Threat	3.13	0.80
Centrality	3.48	0.78
Controllable by self	3.47	0.70
Controllable by others	3.04	1.01
Uncontrollable	2.31	0.93
Adaptive Coping	37.89	5.91
Maladaptive Coping	18.30	3.87
Worry	53.16	12.76

Hypothesis Testing

Hypothesis 1: Affective Flexibility and Examination Stress

Higher time to switch towards the non-affective rule in the presence of positive information predicted higher examination stress (see Table 15).

Table 15. Regression Model with Examination Stress and Uncontrollable Appraisals as Outcome, With All Affective Flexibility Switch Costs as Predictors

	Examination Stress			Perceptions of Uncontrollability		
Predictors	*Std. Beta*	*Standardized CI*	*p*	*Std. Beta*	*Standardized CI*	*p*
Non-Affective Positive SC	**0.21**	**0.03 – 0.39**	**0.021**	0.16	-0.03 – 0.35	0.097
Non-Affective Negative SC	-0.02	-0.19 – 0.14	0.783	0.08	-0.11 – 0.27	0.398
Affective Positive SC	-0.05	-0.23 – 0.13	0.590	0.06	-0.13 – 0.26	0.511
Affective Negative SC	0.03	-0.13 – 0.19	0.720	**-0.20**	**-0.38 – -0.01**	**0.034**
Gender	-0.12	-0.57 – 0.33	0.593	0.16	-0.38 – 0.71	0.553
Chronic Stress	**0.47**	**0.30 – 0.64**	**<0.001**	0.17	-0.02 – 0.37	0.077
Observations	123			116		
R^2 / R^2 adjusted	0.241 / 0.201			0.109 / 0.059		

Note. Gender was coded 1 (men) and 2 (women); Significant predictors are presented in bold; *CI* = Confidence Intervals; *SC* = Switch Cost; *Std* = Standardized.

Hypothesis 2: Affective Flexibility and Appraisals

None of the cognitive flexibility switch costs predicted challenge/threat appraisals. Higher switch costs towards the affective rule in presence of positive information approached significance in predicting lower perceptions of centrality (β = -0.18, p = .055; see Table S4). Finally, affective negative switch cost was a significant, negative predictor of uncontrollable-by-anyone (see Table 15), while none of the affective flexibility switch costs were predictive of other secondary appraisals (see Table S5).

Hypotheses 3 and 4: Coping and Worry

None of the affective flexibility switch costs emerged as significant predictors of adaptive and maladaptive coping, nor of worry (Tables S6 and S7). However, a significant correlation between higher non-affective positive switch cost and lower maladaptive coping did emerge [$r(121)$ = -0.23, p = .009; see Figure S2].

Mediational Models Testing

The mediation model for affective negative switch costs and perceptions of uncontrollability failed to reveal a significant direct, indirect, or total effect. Path a (flexibility on uncontrollability) was not significant (β = -0.13, p = .148), but path b (perceptions of uncontrollability on examination stress) was (β = 0.28, p < .001). Hence, there is no confirmed significant mediation effect of secondary appraisal.

In comparison, the mediation model for non-affective positive switch cost and maladaptive coping revealed a direct (β = 0.25, CI 0.0006 to 0.0036, p = .006) and total (β = 0.21, 95% CI 0.0003 to 0.0033, p = .021) effect, but no indirect effect (CI -0.10 to 0.004). Path a (non-affective positive switch cost on maladaptive coping) was not significant (β =

-0.16, $p = .101$), though path b (maladaptive coping on examination stress) was ($\beta = 0.24$, $p = .005$).

Discussion

The aim of this second study was to extend previous laboratory research on affective flexibility, acute stress reactivity and recovery to a real-life stressor. We chose university examinations as our ecological stressor because they provide a common stress experience for all university students. This approach allowed us to examine how students appraise and regulate their emotions spontaneously before the examination period begins. As with Study 1, it is important to highlight that all but one hypothesis were not confirmed. Nevertheless, we did observe an impact of other affective flexibility switch costs on three aspects of resilience: maladaptive coping strategies, anticipated stress leading up to the first examination, and perceptions of uncontrollability associated with the examination period.

Better Affective Flexibility Towards Non-Affective Processing of Positive Stimuli

Our findings are consistent with prior research (Genet et al., 2013; Grol & De Raedt, 2021) and support our third hypothesis. Better flexibility in switching from affective to non-affective processing of positive stimuli was significantly correlated with higher use of maladaptive coping in anticipation of examination sessions. This suggests that faster disengagement from affective aspects is linked to less functional coping responses. Previous research has also demonstrated such associations between faster disengagement from affective elements of positive stimuli and heightened levels of rumination in response to daily stressors (Genet et al., 2013) and higher employment of maladaptive coping strategies (self-blame, rumination, catastrophizing, other-blame) during an acute laboratory stressor (Grol & De Raedt, 2021). Our study provides further evidence for the fact that taking more time to disengage from the affective aspects of positive stimuli is linked to a lower selection of maladaptive coping strategies. However, it is important to remember that these results emerged from correlational analyses only. On the whole, a degree of *in*flexibility in the context of processing affective aspects of positive content may be adaptive.

In contrast, better flexibility switching from the affective to the non-affective rule when processing positive information was also significantly associated with *less* anticipatory stress ahead of the examinations. Contrary to prior null findings (Grol & De Raedt, 2021), difficulties disengaging from the positive aspects led to sustained stress responses two months later. A similar observation had been reported in the literature for non-affective processing of negative information. Better flexibility from the affective rule in the presence of negative material was associated with more adaptive choices of emotion regulation [e.g., lower rumination (Genet et al., 2013) and higher reappraisal (Malooly et al., 2013)], but also with sustained anxiety and worry in the long run (Twivy et al., 2021).

Improved flexibility might thus favor avoidance of feared stimuli, particularly by quickly shifting focus from affective to non-affective aspects of negative information. Interestingly, our findings revealed that the opposite effect was true when treating positive information instead: better flexibility was linked to less adaptive emotion regulation choices but also to lower self-reported stress. Therefore, the valence under consideration leads to opposite outcomes, which has important clinical implications.

Depending on the desired outcome, different levels of (in)flexibility are warranted. For example, should one wish to reduce self-reported levels of stress during a stressful period ahead of an important event, one should disengage more rapidly from the affective aspects when processing *positive* information. Based on previous research on stress optimization (Crum et al., 2020), we speculate that individuals may be switching towards non-affective aspects of the stimuli instead, such as focusing on event-related goals (*i.e.*, why the examination period is important for their future career), which reduces perceived stress regarding the stressor.

Better Affective Flexibility Towards Affective Processing of Negative Stimuli

Finally, better flexibility from the non-affective to the affective rule when processing *negative* information significantly predicted higher perceptions of uncontrollability regarding the stressor. Thus, faster time to engage with the affective processing of negative information was associated with more uncontrollability. This attentional bias towards negative information may be explained by the vigilance-avoidance model (Borkovec, 1994). Exposure to stressful situation generates an attentional bias to deal with the danger. Here, faster engagement with the affective rule predicted greater uncontrollability, which may have led to subsequent behavioral responses implemented to cope with this uncontrollability. Alternatively, more time engaging with the affective aspects of negative stimuli may be – temporarily – more beneficial for the individual, as it may prevent oneself from forming unnecessary negative appraisals of the situation. To the best of our knowledge, this is the first study to observe a significant association between affective flexibility and measures of appraisals. Replicating Study 1, we provide further evidence for a degree of functionality associated with poorer flexibility, demonstrating that *inflexibility* may be adaptive under specific circumstances.

6.4. General Discussion

Cognitive flexibility when processing affective information may enhance resilience to stress (Rademacher et al., 2023). The two current studies attempted to elucidate contrasting results found in the literature and to extend previous research to the implication of affective flexibility in stress responses. Overall, two affective flexibility switch costs were relevant for subjective stress, appraisals, and affect regulation strategies in response to either a laboratory induction or to an upcoming ecological stressor. Poorer flexibility switching to the affective rule when processing *negative* images significantly predicted more MAST-induced subjective stress (Study 1), lower use of suppression during the stressor (Study 1), and lower perceptions of uncontrollability in anticipation of the examination period (Study 2). In parallel, poorer flexibility switching to the non-affective rule when processing *positive* material significantly predicted greater subjective stress ahead of the examinations (Study 2) and lower maladaptive strategy use to deal with the examination (Study 2).

Affective Flexibility and "Adaptivity"

Overall, our results suggest that better flexibility when engaging with negative affective rules and when disengaging from positive affective rules are associated with less adaptive emotion regulation choices (i.e., higher suppression to acute stress and maladaptive coping ahead of the examinations) and less adaptive appraisals (higher uncontrollability), but also with more adaptive emotional outcomes (lower stress). It is crucial to highlight the separate branching effects of affective flexibility on appraisals, affect regulation strategies, and subsequent stress responses. In both studies, there were no significant mediating effects of either appraisal or maladaptive coping on the relationship between affective flexibility and anticipatory stress. This indicates that the effects of affective flexibility on cognitive, behavioral, and emotional responses to stress not only differ, but they may also follow independent pathways. The adaptive quality of affective flexibility may therefore depend on the outcome under consideration.

Aligned with previous findings, such separated effects for one specific switch costs had already been reported: better flexibility when disengaging from the affective processing of negative material was associated with less rumination (Genet et al., 2013), higher use of reappraisal (Malooly et al., 2013), but also with lower anxiety in the long run (Twivy et al., 2021). Contrary to previous research, we did not observe significant effects for this switch cost. In fact, the significant switch costs identified in our study have seldom been reported in previous literature (Table 11). Thus, it appears that different switch costs may be at play within the context of stress research, but the separation of effects remain consistently reported.

Recent work has emphasized the importance of context when studying affective flexibility and affect regulation (Godara et al., 2021). As situations and context change, individuals must switch between different higher-order goals, which implies subsequent changes in attention allocation towards one's environment. Both positive and negative emotions, as well as strategy selection, are adaptive when considered in the context alongside which they occur. For example, flexibility in redirecting attention away from non-affective aspects (i.e., potential avoidance of affective information) – may not be adaptive in situations where focusing on affective information could enhance coping strategies and bolster resilience (Troy, 2015). This could explain why better flexibility in switching towards affective aspects of negative stimuli during the stressor was associated with higher suppression and lower perceived stress.

Hence, our results demonstrate that (in)flexibility – as measured with this task-switching paradigm – should not be stereotypically categorized as "good" or "bad". Flexibility may have different levels of (dys)functionality. These interesting findings question the relevance of flexible attentional directing. When exposed to a threatening situation, an increase in stress responses is adaptive (*e.g.*, cortisol; Dickerson and Kemeny, 2004). The absence of a cortisol response would be indicative of the hypothalamic-pituitary-adrenal axis performing under optimal threshold (Almela et al., 2014). Thus, what is the "optimal" level of affective task-switching that would promote better affect regulation and overall stress levels? One study has recently revealed an inverted U-shaped association between stress reactivity and subjective well-being, reporting that a "moderate" level of stress reactivity was more optimal, compared to either too-little or too-much (Rush et al., 2024). Future studies could similarly explore the window of affective flexibility "efficiency", that would allow individuals to reach this level of moderate stress when exposed to adversity, whether it being in the laboratory or in ecological settings.

Affect Flexibility: Measurement and Perspectives

The examination of affective flexibility in these studies not only uncovered consistent and distinctive differences in switch costs for stress regulation but also raised questions regarding the measurement of affective flexibility. In both studies, we found consistent and distinctive differences in the duration of the switch costs across all participants (i.e., asymmetric switch costs). Participants experienced a difficult time engaging with the affective aspects of negative stimuli. More specifically, this was represented by better flexibility switching away from processing the affective aspects of negative images, or particularly longer times engaging with them. In contrast, participants were more likely to maintain their attention on the processing of positive stimuli in the presence of positive information or switching to such aspects.

Our findings therefore call into question whether the switch costs calculated with this task represent a proxy of attentional avoidance in processing positive and negative information. It is important to note, however, that this paradigm was initially designed to assess cognitive resources rather than the active deployment of visual attention, and it does not involve shifting of visual attention through gaze movements (Malooly et al., 2013). Therefore, it is impossible, with this task, to disentangle engaging with affective aspects of the stimuli according to the new rule from disengaging from non-affective aspects of the stimuli according to the former rule. Future work, therefore, should incorporate eye-tracking paradigms to evaluate the ability to switch attention, notably from negative to positive stimuli (Godara et al., 2021), while accounting for contextual information.

Researchers must also question the replicability of existing results using this task. For example, the switch costs that arise as significant predictors are not always replicated in the literature. Moreover, other studies implementing different affective flexibility tasks have failed to find differences in attentional shifting for other stress-related outcomes, including trait anxiety (e.g., Van Bockstaele et al., 2024). It is possible, therefore, that affective flexibility is either less involved in processes of resilience than originally thought, or that its effects are heavily dependent on the selected outcome and its measurement. All results presented here are based on only one paradigm of affective flexibility. This study's strength, however, lies in the consistent use of the same paradigm, identical stimuli, and switch cost calculations across all results reviewed in this article, which enhances the potential for replicability.

Research should continue to compare and understand differences between tasks that implement neutral and affective stimuli. Frameworks on executive functioning argue for a continuum to executive functioning from "cool" to "hot" (for a review, see Zelazo, 2020). While the former relates to executive functioning exerted in emotionally neutral contexts, the latter is involved in motivationally salient situations. One of the main limitations of the affective flexibility task used in these studies is that the "non-affective" dimensions of the stimuli are still perceived in an affective context so implementing neutral stimuli. Thus, evaluating how individuals engage in or disengage from neutral to affective stimuli and vice versa may also provide more variability in the performances and be potentially more informative. Then, administering different affective flexibility tasks with simultaneous measures of brain dynamics could further help researchers in the field understand not only the task itself but also the brain areas supporting flexibility.

Finally, the term "flexibility" has been used interchangeably across different research fields, relating, for example, to "psychological flexibility" (Kashdan & Rottenberg, 2010), "expressive flexibility" (Westphal et al., 2010), "coping flexibility" (Cheng et al., 2014), or "emotion regulation flexibility" (Aldao et al., 2015). All approaches have important contributions for resilience and mental health, and should, thus, be integrated for a more comprehensive understanding of how they enable individuals respond emotionally, cognitively, and behaviorally to stressful situations. As seen from our findings, flexibility relating to emotional information is equally important for stress responses and regulation and should be worked into these frameworks.

Limitations

Although these two studies have brought important insight into the study of affective flexibility for stress and resilience, several limitations must be noted. First, it is important to recognize that both studies are of correlational nature. Future work could benefit from further interventional work (Malooly, 2016) while accounting for contextual cues (Godara et al., 2021).

Second, the studies were both conducted on a sample of healthy and young adults. While symptoms of chronic stress were normally distributed in both samples, indicating a large variability of stress, it is possible that affective flexibility deficits may be more likely to be observed in clinical samples. In fact, deficits in cognitive flexibility (e.g., using set-shifting tasks) have been observed across different disorders, including anxiety, eating disorders, and obsessive-compulsive disorders, but research on affective flexibility is rarer. Affective flexibility, therefore, may differ in its impact across community and clinical samples. Nonetheless, our study provides insight on how affective flexibility is involved in healthy participants in the midst of a difficult period where negative mood and important distress are usually observed (i.e., the examination period).

Third, the affective flexibility task was administered online, which may lead researchers to question its validity. It is important to note that three attention-check items were administered at the end of the Study 2 testing. None of these factors correlated significantly with any of the switch costs (see Supplementary Materials). Moreover, the percentages of trials removed from the task were similar to that obtained by other research teams. Finally, the significant difference in time between repetition and switch trials was also replicated in both studies. Thus, this provides evidence for task validity when administered online.

Fourth, participants were not specifically instructed to engage with a specific affect regulation strategy, which may also indicate that individuals were not actively or spontaneously using these, specifically. Nonetheless, it is important to note that the measures of reappraisal, suppression, adaptive and maladaptive coping, and worry were all normally distributed in our samples of interest. In Study 2, however, there were no significant differences between the control and the stressor group in terms of suppression use during the MAST. In contrast, there was a significant difference in the use of reappraisal, where participants undergoing the stress induction were *less* likely to resort to it. Thus, this may suggest that, under stress, individuals may be less likely either to use or to report using such strategy. For example, in an ecological momentary assessment study (Socastro et al., 2022), higher stress controllability during low-stress situations led to more use of reappraisal and rumination, while under high-stress situations, higher controllability led to less rumination. Future work could combine our Study 1 design with Malooly and colleagues (2013)'s to ensure that participants actually implement an affect regulation strategy. For example, participants could be allocated to either the MAST or the placebo-MAST, and then either (1) instructed to explicitly reappraise their stress and associated affect, or (2) given no specific instructions. This would allow researchers to compare spontaneous and instructed use of diverse affect regulation strategies.

Fifth, another limitation is the use of self-report measures across both experiments. As we have seen, participants were potentially more active in avoiding the processing of negative information during the affective flexibility task, which may be associated with emotional avoidance. Thus, the extent to which individuals under-reported their own stress, appraisals or affect regulation simply by not being aware of them or not being willing to report them is a real concern. Future studies combining psychological and physiological measures could further shed light on the relationship between affective flexibility and stressor resilience.

6.5. Conclusion

This article reports the results from two studies investigating the role of affective flexibility for stress, appraisals, and affect regulation. Two affective flexibility switch costs were significantly associated with stress regulation. Study 1 found that poorer flexibility when switching from the non-affective to the affective aspects of negative material predicted higher changes in self-reported stress after the stressor and lower expressive suppression during it. In Study 2, it also predicted lower perceptions of uncontrollability ahead of the upcoming examination session. Additionally, poorer flexibility when switching from the affective to the non-affective rule in presence of positive material led to greater anticipatory stress ahead of the examinations and lower use of maladaptive coping choices. Overall, this indicated that poorer flexibility was associated with more adaptive emotional stress responses (i.e., lower stress reactivity), but, in contrast, it also related to higher behavioral stress responses traditionally considered maladaptive. These findings question the relevance of categorizing affective flexibility, appraisals, and affect regulation strategies as adaptive and maladaptive. We argue that these can present different degrees of functionality depending on the situation in which they are observed. Future research should focus on investigating the cognitive factors that underly resilience while accounting for the contextual factors associated with it.

Table 16. Affective Flexibility Task Switch Costs Calculations

Switch Costs	Trial Abbreviation	Trial Type	Trial Description
1. Affective positive switch cost: $RT_{pos\_naff \rightarrow pos\_aff} - RT_{pos\_aff \rightarrow pos\_aff}$, where poorer flexibility (i.e., higher RT switch costs) indicates greater difficulties in switching from the non-affective rule to the affective rule, in the presence of positive stimuli.	Pos_naff → Pos_aff	Switch	Trial with positive image and affective task rule that was preceded by a trial that was a positive image with non-affective task rule
	Pos_aff → Pos_aff	Repetition	Trial with positive image and affective task rule that was preceded by a trial that was also a positive image with affective task rule
2. Affective negative switch cost: $RT_{neg\_naff \rightarrow neg\_aff} - RT_{neg\_aff \rightarrow neg\_aff}$, where poorer flexibility (i.e., higher RT switch costs) indicates greater difficulties in switching from the non-affective rule to the affective rule, in the presence of negative stimuli.	Neg_naff → Neg_aff	Switch	Trial with negative image and affective task rule that was preceded by a trial that was a negative image with non-affective task rule
	Neg_aff → Neg_aff	Repetition	Trial with negative image and affective task rule that was preceded by a trial that was also a negative image with affective task rule
3. Non-affective positive switch cost: $RT_{posaff \rightarrow pos\_naff} - RT_{pos\_naff \rightarrow pos\_naff}$, where poorer flexibility (i.e., higher RT switch costs) indicates greater difficulties in switching from the affective rule to the non-affective rule, in the presence of positive stimuli.	Pos_aff → Pos_naff	Switch	Trial with positive image and non-affective task rule that was preceded by a trial that was a positive image with an affective task rule
	Pos_naff → Pos_naff	Repetition	Trial with positive image and non-affective task rule that was preceded by a trial that was also a positive image with non-affective task rule
4. Non-affective negative switch cost: $RT_{neg\_aff \rightarrow neg\_naff} - RT_{neg\_naff \rightarrow neg\_naff}$, where poorer flexibility (i.e., higher RT switch costs) indicates greater difficulties in switching from the affective rule to the non-affective rule, in the presence of negative stimuli.	Neg_aff → Neg_naff	Switch	Trial with negative image and non-affective task rule that was preceded by a trial that was a negative image with an affective task rule
	Neg_naff → Neg_naff	Repetition	Trial with negative image and non-affective task rule that was preceded by a trial that was also a negative image with non-affective task rule

Note. *RT* = Response Time. *Negaff = Negative image with affective rule; Negnaff* = Negative picture with non-affective rule; *Posaff* = Positive image with affective rule; *Posnaff* = Positive image with non-affective rule. Greater switch costs indicate less efficient shifting and, therefore, poorer flexibility.

Section 4.

General discussion

Chapter 7.

General Discussion

Over 970 million individuals suffer from stress-related mental disorders across the world (World Health Organization, 2019). On occasions when we encounter a stressor, our brain sends a series of signals to generate adaptive stress responses that allow our bodies to cope with the perceived threat. Frequent or prolonged stressful events without adequate recovery time can lead to significant long-term damage to the body's stress systems. Understanding how individuals maintain health under adversity and stress, otherwise known as resilience, must be a priority in research agendas (Bonanno et al., 2023; Kalisch et al., 2017). Identifying mechanisms to buffer against stress is fundamental for promoting healthy outcomes, treating stress-related mental health disorders, and preventing stress-related physical illnesses (Gee & Casey, 2015). This PhD thesis explored whether executive functioning could contribute to more adaptive stress responses. As illustrated in Figure 22, the aims of this thesis were two-fold:

1. To investigate the protective role of different executive functioning facets with respect to acute stress responses.

2. To explore the extent to which cognitive and behavioral processes are implicated, including cognitive stress appraisals and affect regulation strategies.

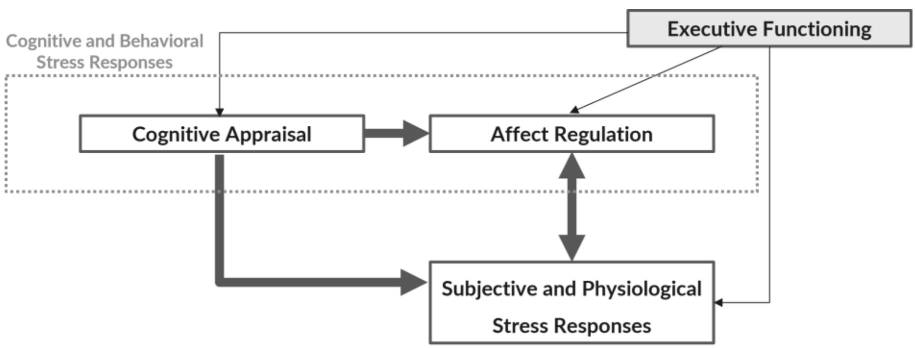

Figure 22. PhD Theoretical Framework

The general discussion begins by providing a summary of each study's findings. Next, we separately discuss each association from the model that corresponds to the PhD Theoretical Framework (Figure 22). Next, we discuss the theoretical, methodological, and clinical implications of the findings. Finally, the general limitations and perspectives for future research on executive functioning and acute stress responses are discussed.

7.1. Summary of Findings

The systematic literature review and meta-analysis in **Chapter 2** was conducted to identify whether executive functioning and working memory capacity, when measured ahead of a laboratory-induced stressor, were significant predictors of subsequent anticipation, reactivity, and recovery to the stressor. The systematic review found that attentional control was most consistently associated with acute stress, with mixed results observed for inhibition, cognitive flexibility, updating, and working memory capacity. A robust variation estimation meta-analysis on available data revealed a small, significant, and negative correlation between higher **working memory** and subsequent lower cortisol reactivity. These results highlighted (a) the potential for executive functioning in accounting for acute stress responses, (b) the scarcity of relevant data and designs investigating this specific directionality of the association, as well as (c) the need for interventional designs and the consideration of mediators to understand underlying mechanisms, including appraisals, rumination, and coping.

Chapter 3 investigated this association in an ecological design, in a sample of 133 undergraduate students. It explored the role of different executive functioning facets (inhibition, cognitive flexibility, updating), working memory capacity, and planning in anticipatory stress levels ahead of the university examinations Although we hypothesized that all six cognitive tasks would directly and significantly predict lower anticipatory stress, none of the executive functioning facets showed a significant effect. However, maladaptive coping was a significant mediator between **cognitive flexibility** and anticipatory stress, while worry served as a significant mediator between **planning** and anticipatory stress.

Chapter 4 focused on replicating the results for these associations in the context of an acute stressor induced in laboratory settings. This study, conducted on a sample of 138 participants, examined the role of inhibition, cognitive flexibility, updating, and working memory capacity in predicting physiological and subjective stress across different phases of anticipation, reactivity, and recovery. Our hypothesis stipulated that inhibition, cognitive flexibility, updating, and working memory capacity would be significantly associated with lower stress reactivity in response to the stressor and with faster recovery to baseline after the stressor. However, only two of these facets showed significant associations, and only for particular stress outcomes. Specifically, poorer **cognitive flexibility** was associated with higher anticipatory blood pressure and skin conductance levels after receiving MAST instructions. Additionally, lower **inhibition** was linked to higher systolic blood pressure and lower skin conductance levels in anticipation of the stressor. Lower **cognitive flexibility** was associated with higher skin conductance levels during the stressor period compared to baseline, indicating greater reactivity. For recovery, poorer **cognitive flexibility** correlated with increased systolic blood pressure, mean skin conductance levels, and self-reported stress levels after the resting period compared to baseline, signifying worse stress recovery. Additionally, poorer **inhibition** predicted worse heart rate recovery. We found no evidence that cognitive appraisals, repetitive negative thinking, or emotion regulation mediated these associations.

Chapter 5 strived to extend previous results in daily life, using an ecological momentary assessment paradigm. A total of 120 participants completed tasks measuring inhibition, cognitive flexibility, updating, and working memory capacity before completing a six-day protocol consisting of six notifications per day. Our hypothesis was that executive functioning, particularly cognitive flexibility, would significantly predict (a) lower stress levels when exposed to a stressful event, (b) reduced proximal and cumulative reactivity to daily stressors, and (c) faster immediate and cumulative recovery. We found that only higher **working memory capacity** predicted lower stress levels when individuals were exposed to a stressful event. Moreover, none of the executive functioning facets significantly predicted stress reactivity and recovery indices. Additionally, appraisals and affect regulation strategies did not mediate the relationship between executive functioning and stress responses.

The study further explored the overlapping concepts of cognitive flexibility, as measured in the field of neuropsychology, and flexibility in affect regulation strategies, as captured through variability and flexibility in strategy implementation. Our hypothesis was that working memory capacity and cognitive flexibility would be significantly associated with variability and flexibility in affect regulation. However, these expectations were not fully supported. **Poorer cognitive flexibility** was correlated with greater within-variability in adaptive strategies and greater between-variability in maladaptive strategies. However, only **inhibition** remained significant in the regression models, with poorer levels predicting greater variability in adaptive affect regulation strategies. Finally, none of the executive functioning facets were significantly associated with flexibility in affect regulation strategies.

Given the predominant role played by cognitive flexibility in previous chapters and studies, **Chapter 6** aimed to replicate these effects using emotional stimuli. In Study 1, participants completed an affective set-shifting task and, similar to Chapter 4, were randomly assigned to an experimental (N = 87) or control (N = 43) version of the MAST. We hypothesized that (1) better flexibility switching to the *non-affective* rule when processing *negative* material, and (2) poorer flexibility in switching to the *affective* rule in the presence of *positive* material would predict higher reported stress after the MAST. Instead, we found that better flexibility in switching to the *affective* rule when processing *negative* material was associated with *lower* reported stress and greater use of suppression during the stressor. This latter finding, related to suppression, was contrary to our initial hypothesis, while all other hypotheses concerning appraisal, reappraisal, or suppression were not confirmed.

In Study 2, similar to Chapter 3, university students (N = 123) completed the same affective flexibility task two months before their end-of-year examinations. Regarding anticipatory stress, we hypothesized that poorer flexibility switching to the *affective* rule when processing (1) *negative* and (2) *positive* material, as well as (3) better flexibility to the *non-affective* rule in presence of *negative* material, would predict greater stress. Better flexibility in switching to the *affective* processing of *negative* stimuli was also associated with higher appraisals of uncontrollability, which was surprising given that the absence of previous results had led us to expect no relationship between the two constructs. All other expected hypotheses for appraisal and coping were not verified.

These two studies confirmed the importance of flexibility for stress regulation and highlighted its distinct effects on emotional and behavioral stress responses. They suggest that better flexibility can lead to more adaptive emotional responses, but less adaptive appraisals and affect regulation choices. We argue for the consideration of context when evaluating affective flexibility and affect regulation as adaptive or maladaptive, in line with recent affect regulation frameworks.

Overall, it is imperative to note that the PhD study results were rarely aligned with the initial hypotheses, particularly regarding specific executive functioning facets. Nevertheless, it is noteworthy that some of the general anticipated relationships between constructs outlined in the PhD Theoretical Framework (Figure 22) were partially confirmed. First, direct effects for executive functioning on stress were found (a) for psychological and physiological responses to the acute stress in the laboratory (Chapters 4 and 6), (b) when predicting stress affect while reporting stressful events in daily life (Chapter 5), and (c) with respect to anticipatory stress ahead of examinations (Chapter 6). Second, we found no evidence for the association between executive functioning and appraisal processes. The only exception was in Chapter 6, where affective flexibility was associated with appraisals of uncontrollability. Third, executive functioning was associated with a variety of affect regulation strategies across Chapters 3 to 6. However, the mediating effects of cognitive appraisal and affect regulation were only significant for anticipatory stress in the context of examination stress (Chapter 3). In the next section, I pool together these results across all studies to provide a comprehensive understanding of the findings and their replication.

7.2. Theoretical and Methodological Implications

Executive Functioning and Acute Stress Responses

In general, better inhibition, cognitive flexibility, and working memory capacity were associated with lower anticipation, reactivity, and better recovery (with two exceptions discussed in the respective chapters; see Table 17). Hence, these results provide preliminary evidence for Williams and colleagues' (2009) integrative and developmental model of individual differences in executive functioning and stress regulation. They suggest that individuals with poorer executive functioning – inhibition, cognitive flexibility and working memory capacity, specifically – may be more susceptible to enhanced physiological and psychological reactivity to acute stressors, as well as prolonged stress activation after their termination. Importantly, they also extend these findings to anticipatory stress, a construct that was not under consideration by the original framework.

A first important observation from the PhD studies stems from the fact that there is a *direct* link between executive functioning and stress. The systematic review hinted at potential mediators of this association, but we provide evidence for executive functioning directly playing a role.

A second important observation is that the executive functioning facets emerging as significant and relevant for acute stress response vary depending to the study design (as summarized in Table 17). For example, cognitive flexibility was the only facet consistently and significantly associated with a stress outcome, but only across two studies. In contrast, inhibition was a significant predictor of stress in Chapter 4, but its effect on anticipation were contradictory: it predicted lower blood pressure while being associated with higher skin conductance response. Working memory capacity was only a significant predictor of lower stress responses in Chapter 5. While these results are intriguing, it is also important to note that they rarely aligned with the pre-registered hypotheses. As outlined in the *Summary of the Findings* section, none of the hypotheses were fully supported, despite being grounded in previous, albeit limited, research. These discrepancies are noteworthy, given that the cognitive task administered were consistent across studies, and that all cognitive tasks were always included as simultaneous predictors in the statistical models. This highlights a critical methodological consideration regarding the measurement of stress in current research. More specifically, it calls into question whether researchers studying these relationships across different designs truly capture the same stress constructs. Given the relative instability of these associations across contexts, extensive replication work is needed to establish their reliability. I discuss these issues further in the study limitations.

A third and final observation is that while this association between executive functioning and stress may be interesting and promising for future interventions, research now needs to understand more precisely *how* and *why* executive functioning protects against excessive stress responses. While Williams and colleagues (2009) outline the theoretical reasons for the implication of executive functioning, work should now focus on the integration of neurobiological research. This is especially true because previous models linking executive functioning to stress highlighted the implications of other variables, such as affect regulation. However, the link here being direct prompts numerous questions regarding the reasons behind this phenomenon.

Table 17. Overview of Significant Results between Executive Functioning and Acute Stress Responses

Executive Functioning	Chapter 3 (Ecological Setting)	Chapter 4 (Laboratory Setting)	Chapter 5 (Daily Stress)	Chapter 6 (Ecological and Laboratory Settings)
Inhibition		• Lower anticipatory blood pressure and higher skin conductance • Better heart rate recovery		N/A
Cognitive Flexibility		• Lower anticipatory blood pressure and skin conductance • Lower skin conductance reactivity • Better recovery in terms of blood pressure, skin conductance, and subjective stress		• Lower post-MAST stress (Better flexibility switching to the affective rule in presence of negative stimuli) • Lower examination stress (Better flexibility switching to the non-affective rule in presence of positive stimuli)
Updating				N/A
Working Memory Capacity			• Lower proximal reactivity and recovery[1] • Lower stress affect when exposed to a stressor	N/A

Note. [1] indicates correlations; *N/A* = Not applicable; Executive functioning scores relate to *better* scores on the tasks; Empty table cells indicate an absence of significant associations between these variables.

Responses to psychosocial stressors originate in higher brain regions, such as the prefrontal cortex and interconnected limbic nuclei (for a complete description of brain areas involved, see Moses et al., 2023). Figure 23 illustrates the implication of three brain areas in the response to acute stressors (Ulrich-Lai & Herman, 2009). First, the "bottom-up" stage responds to homeostatic imbalance signals (e.g., pain and inflammation) and is monitored by the brainstem. Brainstem connections to the midbrain and the forebrain integrate, modulate, and monitor sympatho-adrenomedullary responses. Second, the hypothalamus and the bed nucleus of the stria terminalis (BNST) play a major role in the second, or middle-management, of psychosocially-mediated SAM and HPA responses (Ulrich-Lai & Herman, 2009). The BNST, a grey matter structure within the amygdala, represents a specific relay site for the HPA axis specifically. Third, the "top-down" stage occurs in forebrain areas, such as the prefrontal cortex, amygdala, and hippocampus, which process higher-order sensory inputs and ascending signals, modulating responses to both physiological and psychological stressors (Moses et al., 2023).

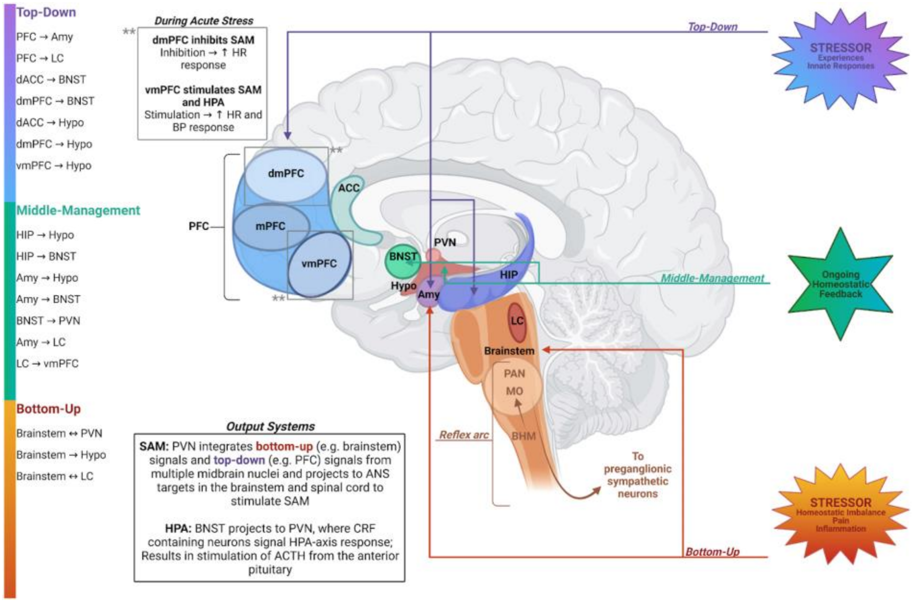

Figure 23. Overview of Brain Regions involved in the Neural Regulation of Acute Stress Responses

Note. ACC = anterior cingulate cortex; *Amy* = amygdala; BHM = brainstem homeostatic monitors; *BNST* = bed nucleus of the stria terminalis; CRF= corticotropin-releasing factor; *dlPFC* = dorsolateral prefrontal cortex; *dmPFC* = dorsomedial prefrontal cortex; *HIP* = hippocampus; Hypo = hypothalamus; *MO* = medulla oblongata; *mPFC*: medial prefrontal cortex; *PAN* = pre-autonomic neurons; *PVN* = paraventricular nucleus of the hypothalamus; *vmPFC* = ventromedial prefrontal cortex. Figure copied from Moses and colleagues (2023). Permission from Elsevier not required for this non-commercial use.

During exposure to stressful events, there may be a primacy effect of the bottom-up processes where signals from areas such as the hypothalamus and amygdala may influence higher cortical structures (such as the medial prefrontal cortex; Flores-Kanter et al., 2021; Weis et al., 2019). Meanwhile, psychosocial stressors may exert a “top-down” effect, with forebrain areas processing stress first, decreasing amygdala activation (Flores-Kanter et al., 2021), and indirectly altering physiological homeostasis (Moses et al., 2023). Affect regulation strategies may be also implicated at this stage, as a number of studies have found such strategies to also be associated with prefrontal activation. While we will discuss the implications of these strategies later, this top-down initiation provides preliminary explanations for how different brain areas – and, perhaps, executive functioning – may modulate stress responses at the neural level.

In alignment with the idea that cognitive control may be implicated in regulating stress responses, experimental modifications of the prefrontal cortex has led to modifications of stress responses. For example, one sham-controlled high frequency repetitive Transcranial Magnetic Stimulation (r-TMS) session applied to the left dorsolateral prefrontal cortex led to significant reductions in cortisol release by the HPA axis during a stress induction (Baeken et al., 2014). However, pathways through this region of the prefrontal cortex affects the HPA axis still require further examination to fully comprehend the mechanisms involved. Integration work must be completed to understand how neuropsychological markers also contribute to this effect. I believe that future perspectives should focus on neuroscience approaches to executive functioning and stress.

Executive Functioning and Cognitive Appraisals

As discussed throughout Chapters 3-6, however, there is very limited evidence for executive functioning predicting cognitive stress appraisals ahead of stressors. The only significant effect was observed for affective flexibility and appraisals of uncontrollability ahead of the upcoming university examination session (Chapter 6). In all other chapters, we were unable to reproduce previous studies having investigated this effect (Panganiban & Matthews, 2014; Zandara et al., 2016). Yet, there is evidence of interactions between brain regions involved in both executive functioning and generating emotion appraisals (Flores-Kanter et al., 2021). For example, the temporal lobes are thought to modulate the emotional response based on the context, assessing and attributing emotional significance by integrating complex information from the environment. The amygdala, meanwhile, may be involved in making a rapid assessment of emotional significance (Park et al., 2019). Therefore, while executive functioning may still be theoretically implicated in the creation of appraisals, our findings do not support this idea. We discuss potential reasons for this in respective chapters and review the evidence for the implication of executive functioning in stress regulation.

An additional explanation, however, for the absence of findings may be the methodological design of the studies. Given that appraisals were measured using self-reports, they were subject to a number of biases, including recall bias. Moreover, measures of stress and stress appraisals sometimes overlap, questioning the conceptual differences between the two (Moses et al., 2023). For example, questionnaires assimilating perceptions of threat as a measure of anxiety or worry (e.g., such as in the Primary and Secondary Appraisal Scale; Gaab et al., 2005), while it should remain separated from negative affect (for a brief discussion, see Grimm et al., 2024 in Appendix A). Furthermore, future studies should focus on implementing experimental designs that capture and manipulate in-the-moment appraisals of stressful events. For example, similar to inductions of repetitive negative thinking, researchers may attempt to induce specific appraisals and examine how this relates to executive functioning tested beforehand (Moore et al., 2015; Tomaka et al., 1997).

In the context of stress research, there are a number of other theories and associated questionnaires to measure stressor appraisals (for a review of available questionnaires of stress appraisals, see Carpenter, 2016). This thesis primarily focused on Lazarus and Folkman's (1984)'s model of stress appraisal and coping. The later postulates that challenge and threat manifest themselves separately and concurrently, each along their own continuum (e.g., Meijen et al., 2020; Skinner & Brewer, 2002). Models originating from sports research also support the idea of a dual activation of challenge and threat appraisals (for a comprehensive review, see Uphill et al., 2019, and the evaluative space approach to the challenge and threat model). However, our work on refining the Stress Appraisal Measure (see Appendix A) revealed that the scale was more aligned with the biopsychosocial model of challenge and threat (Blascovich, 2008). The latter emphasizes that challenge and threat cannot coexist simultaneously (Hase, 2019), with a continuum ranging from an 'adaptive' to a 'maladaptive' state, representing challenge and threat, respectively. Meanwhile, appraisal approaches in the field of emotion research propose different, more dimensional methods to capture emotion appraisal. Specifically, there is a focus on valence, control, agency, novelty and arousal (Hollenstein, 2015; Scherer & Moors, 2019). Although the first two were briefly considered in Study 1 of Chapter 6, they could also be more developed in their relationship with executive functioning, as well as in combination with neural studies in stress. Bridging different theories across the stress and emotion research domains should represent an important agenda for research.

Regarding the work on appraisal questionnaires, it is important to note that they are often constructed in relation to specific chronic stressors, such as a how one deals with a chronic illness. A review by Carpenter (2016) revealed only five "theoretically sound" instruments that measure cognitive stress appraisals. Therefore, there is much to be done regarding adapting these scales to other stress contexts and to, generally speaking, develop accurate self-reported scales.

Finally, a number of other factors may influence stressor appraisals, such as emotional intelligence, neuroticism, extraversion, and perfectionism (for a review, see Kilby et al., 2018). These were not accounted for in the current thesis yet should be considered for future studies. Finally, exploring the neural bases connecting executive functioning to stress appraisals offers promising future research opportunities to better understand this association (Tsai et al., 2019).

Executive Functioning and Affect Regulation

Across all studies of this thesis, we found evidence for associations between executive functioning and the strategies used to regulate stress (see Table 18). Among the facets of executive functioning, cognitive flexibility was found to be the most relevant for affect regulation. Poorer flexibility was associated with more maladaptive coping, such as increased worry and rumination, as well as to more adaptive affect regulation strategies, like creative-dendritic thoughts and acceptance. In contrast, inhibition and working memory capacity had minimal, if any, relevance for affect regulation strategies. Updating was associated with fewer creative-dendritic repetitive thoughts in anticipation of a stressor (Chapter 4) and with higher use of adaptive affect regulation strategies when dealing with daily stressors (Chapter 5). Similarly to the findings for stress responses, a major observation is the absence of consistency across study results, despite identical executive functioning tasks implemented throughout Chapters 3-5.

Table 18. Overview of Results between Executive Functioning and Affect Regulation

Executive Functioning	Chapter 3 (Ecological Setting)	Chapter 4 (Laboratory Setting)	Chapter 5 (Daily Stress)	Chapter 6 (Ecological and Laboratory Settings)
Inhibition			• Lower adaptive affect regulation between-variability	N/A
Cognitive Flexibility	• Lower maladaptive coping[1] and worry[1]; • Maladaptive coping significantly mediated the relationship between cognitive flexibility and anticipatory stress	• Higher reactive creative-dendritic thoughts[1]	• Higher acceptance[1] and reflection[1] • Lower rumination[1] • Lower adaptive affect regulation within-variability[1] and lower between-variability in affect regulation strategies[1]	• Higher suppression (Better flexibility switching to the affective rule in presence of negative stimuli) • Higher maladaptive coping (Better flexibility switching to non-affective rule in presence of positive stimuli)[1]
Updating		• Lower anticipatory creative-dendritic thoughts[1]	• Higher solution-seeking[1] • Higher endorsement of adaptive strategies[1]	N/A
Working Memory Capacity			• Higher solution-seeking[1]	N/A
Planning	• Lower worry[1] and adaptive coping[1] • Worry significantly mediated the relationship between planning and anticipatory stress	N/A	N/A	N/A

Note. [1] indicates correlations. *N/A* = Not applicable; Executive functioning scores relate to *better* scores on the tasks; Empty table cells indicate an absence of significant associations between these variables.

Affect Regulation Strategies

Our results align with existing frameworks and empirical evidence linking executive functioning to emotion regulation (Crum et al., 2020; Hendricks & Buchanan, 2016; Johnson, 2009; Pruessner et al., 2020; Schmeichel & Tang, 2015; Zelazo & Cunningham, 2007). Neuroimaging studies have demonstrated that both executive functioning and affect regulation may be subserved by a frontoparietal network (for a review, see Pruessner et al., 2020). For example, the ability to reappraise emotional material is associated with greater activity of the ventromedial prefrontal cortex (typical executive functioning-related region) and lower activity in regions involved in emotional responding (Buhle et al., 2014; Ochsner & Gross, 2005).

In the self-regulation research field, Hofmann and colleagues (2012) initially suggested that (a) set shifting would be involved in switching between methods that serve the same goals and/or between goals; that (b) inhibition was involved in deactivating goal-unrelated impulses and behaviors; and that (c) working memory would be involved in activating goals, directing attention towards goal-related information, shielding goals from interference, suppressing ruminative thinking, and regulating unwanted emotions, desires or cravings.

Building on this theoretical framework in the field of emotions, Schmeichel and Tang (2015) proposed that reappraisal was dependent on the controlled retrieval of suitable appraisals from working memory (updating), the suppression of undesired appraisals in favor of desired interpretations (inhibition), and the switching from goal-irrelevant to goal-relevant appraisals and narratives (cognitive flexibility). The Selection, Optimization, and Compensation with Emotion Regulation theory (SOC-ER; Opitz et al., 2012; as cited in Toh, 2024) further states that individuals with lower cognitive resources will choose less cognitively-demanding emotion regulation strategies, such as avoidance, compared to other more demanding options, like reappraisal.

The results from this thesis seem to find more evidence for the involvement of cognitive flexibility and updating in regulation. In the unity/diversity framework, specific variance is attributed to these two facets (Miyake & Friedman, 2012). Thus, the implication of executive functioning in stress regulation may not solely depend on general executive functioning but rather on these specific facets. This distinction has significant implications for intervention strategies, which we discuss in a subsequent section.

One must also acknowledge the consistent association between better cognitive flexibility and lower repetitive negative thinking throughout Chapters 3 to 5. This finding is especially robust, as the set-shifting measure remained the same while measures of repetitive negative thinking differed in each study. Our results replicate studies and meta-analyses reporting poor cognitive flexibility as a risk factor for negative repetitive thinking (Vălenaş & Szentágotai-Tătar, 2017; Whitmer & Banich, 2007; Yang et al., 2017). The results also align with the H-EX-A-GO-N model (Watkins & Roberts, 2020), which denotes the relevance of executive functioning for monitoring, shifting, updating, or discarding of irrelevant information and thoughts from working memory. When accounting for all facets of executive functioning, as well as working memory capacity, only cognitive flexibility appears to be relevant for this construct.

Another related observation is that the affective flexibility task was not significantly associated with measures of repetitive negative thinking. This indicates that a general capacity for cognitive flexibility – and not specifically based on treating emotional information – appears to be particularly important for reducing negative repetitive thinking, either as a “trait” (i.e., tendency to worry, in Chapter 3), “state” (i.e., ruminating/worrying in response to an event in Chapter 5), or “mode” (i.e., creative-dendritic thoughts in Chapter 4). Based on our results, we suggest that interventions focusing on *training* executive functioning with the aim of improving repetitive negative thinking should focus on training set-shifting, specifically. I discuss the manipulation of executive functioning in a later section.

Finally, we did not find evidence implicating inhibition in affect regulation strategies, including repetitive negative thinking. This is somewhat surprising given that previous meta-analyses found significant but small associations (Vălenaş & Szentágotai-Tătar, 2017; Yang et al., 2017). It is possible that the sample sizes in this thesis were insufficient to detect very small effects, especially when accounting for other facets simultaneously. Another meta-analysis (Zetsche et al., 2018) revealed the effect to be specific to the resistance to proactive interference (i.e., ability to discard no longer relevant information from working memory). Therefore, different paradigms of inhibition might be more relevant for this association (Verbruggen & Logan, 2008). The meta-analyses primarily focused on Go/No-Go tasks, whereas this thesis implemented the Stop-Signal Task. Both tasks involve repeatedly performing a motor response (e.g., key pressing) to visual stimuli, with occasional pre-defined "stop" signals (visual or auditory) instructing participants to inhibit their response. The main difference is the timing of the inhibitory signal (Littman & Takács, 2017). In the Go/No-Go task, the stop signal appears simultaneously with or instead of the go stimulus. In a Stop-Signal Task, the stop signal appears after the go stimulus, during the response process. A distinction has been proposed, where the Go/No-Go task measures action restraint (i.e., deciding whether to respond), while the Stop-Signal Task measures action cancellation (i.e., stopping an already initiated response, as the default is always to respond; Schachar et al., 2007). Accordingly, both tasks appear to recruit different brain mechanisms (Raud et al., 2020). When evaluating the associations between repetitive negative thinking and inhibitory control, the choice of task and sample size may have a significant impact on the detection of small effects. Notably, while inhibition did not correlate with affect regulation strategies, it did predict stress responses directly, indicating a direct role of inhibition in stress.

Affect Regulation Flexibility and Variability

Beyond the implication of distinct facets of executive functioning for specific strategy implementation, more recent frameworks propose that executive functioning may be implicated in the flexible implementation of affect regulation strategies (i.e., *emotion regulation or coping flexibility*). We discuss this concept throughout the PhD studies, namely to understand surprising findings. For example, better planning (measured using an executive functioning task) predicted lower adaptive coping in Chapter 3, while better flexibility switching to the affective rule in presence of negative stimuli predicted higher use of suppression in Chapter 6. We argue that better executive functioning may not always lead to outcomes one would have qualified as "adaptive". Historically, lower adaptive coping and higher suppression, for example, are not considered constructive for individuals (Aldao et al., 2010). However, accounting for the context is extremely important and aids in understanding the function of the selected strategy. For example, in Chapter 3, better planning capacity in students perhaps encouraged them to adopt a self-reliant coping style, handling stressful situations on their own rather than seeking support from others. In the case of the laboratory stressor (Chapter 6), suppressing one's emotions in response to the stressor may have served an adaptive purpose in this context, as we had led participants to believe that their emotions would be analyzed.

A major theoretical framework bridging the concepts of executive functioning and affect regulation flexibility is the Cognitive Control Framework of Emotion Regulation (Pruessner et al., 2020). This model highlights the role of different executive functioning facets recruited for strategy stopping and switching, strategy maintenance, and monitoring. In their review, English and Eldesouky (2020) emphasized the promise of ecological momentary assessment in order to provide an overarching framework to the elusive concept that affect regulation flexibility currently represents. Using an emotion regulation task, Toh and Yang (2024) found that working memory updating was associated with greater variability and higher frequency in affect regulation switching in high- compared to low-intensity emotional stimuli.

A number of indices have been suggested to capture flexibility and variability. Given the dynamic nature of affect regulation, we opted for calculating measures of affect regulation flexibility and variability using the ecological momentary assessment data we collected for Chapter 5. This study provided preliminary support for the idea that cognitive flexibility, tested using a neuropsychological task, was in fact associated with these indices. Although the calculated indices do not measure strategy stopping and switching per se (as defined by Pruessner and colleagues, 2020), they do give a specific indication on how the individual tends to respond when faced with a stressful event. More precisely, we know *what* strategies they implement and *to what extent.* Although limited by their correlational nature, these findings remain promising for future research, prompting the need for future work that can elucidate how these different constructs interact at the neural, cognitive, and behavioral level.

7.3. A Special Case for (Cognitive) Flexibility

It is important to discuss the consistent effect found in our studies for cognitive flexibility. This term refers to the ability to switch from one task to another, such as moving from writing an email to answering a phone call (Egner & Siqi-Liu, 2024). This process involves replacing one task set, a set of rules connecting stimuli to actions, with another within working memory. Task-switching incurs a cognitive cost, reflected in slower and less accurate responses compared to repeating the same task (Braem & Egner, 2018; Dreisbach & Fröber, 2019). The size of this switch cost is often viewed as an (inverse) measure of cognitive flexibility, where a smaller switch cost indicates greater flexibility.

As seen from Tables 17 and 18 of the General Discussion, this specific executive functioning task (a) predicted subjective and physiological stress, directly; (b) was indirectly associated with anticipatory examination stress, via maladaptive coping; and (c) was associated with a series of affect regulation strategies. Furthermore, cognitive flexibility was also correlated with indices of affect regulation variability, indicative of lower ability to vary one's affect regulation strategies across different daily stressors (Aldao et al., 2015; Blanke et al., 2020; Elkjær et al., 2022). Finally, affective flexibility assessed through an emotional task was also a significant predictor of stress responses and regulation strategies in both ecological and laboratory studies. These observations warrant a closer look at the construct of flexibility itself.

In this PhD thesis, we focused on the neuropsychological definition of flexibility, measuring it exclusively through a task-switching paradigm, where participants switch between different task rules, sets, stimuli, and/or responses (for a review, see Dajani & Uddin, 2015). In our study, this variable was particularly relevant for both acute stress responses and affect regulation. Recent conceptualization on cognitive flexibility consider it to be the "pinnacle" of cognitive control, representing some form of *metacontrol* (Braem & Egner, 2018). While control processes like selective attention and response inhibition may be important for maintaining goals, the overarching ability to flexibly change these goals and tasks is what may foster adaptive behavior. In the last five years, there has been tremendous interest for the concept of cognitive flexibility and its measurement (for recent discussions on flexibility-rigidity, for example, see Dreisbach & Fröber, 2019; Dreisbach & Mendl, 2024; Qiao et al., 2023). As we advanced throughout the PhD studies, however, we encountered other notions of flexibility.

First, we addressed *physiological/autonomic* flexibility in the laboratory study, which refers to the ability to appropriately mobilize physiological resources in proportion to the level of threat (Madison, 2021). We also introduced the concept of *affect regulation flexibility* (Aldao et al., 2015) as a potential research avenue in Chapters 2 and 3 and integrated a indices for this construct in Chapter 5. Though we do not find significant associations for affect regulation flexibility (calculated as the ICC across strategies), there are links between cognitive flexibility (set-shifting) and affect regulation *variability*. Third, we extended the role of cognitive flexibility to that of *affective* flexibility in Chapter 6, demonstrating that *better* flexibility is not always associated with adaptive outcomes. The valence of the material being treated may have a particular influence for stress and affect regulation, as I discuss in the next section.

This thesis was not initially solely focused on cognitive flexibility, yet cognitive flexibility emerged as particularly relevant variable for acute stress and its regulation. Theories on executive functioning and cognitive flexibility have generated a certain ambiguity regarding the core characteristics of these abilities (Dajani & Uddin, 2015). Ionescu (2012) raised the concern that cognitive flexibility lacks a standardized definition, leading to diverse constructs being labelled under the same term. In fact, the term "flexibility" is used across various research fields to refer to different concepts, relating, for example, to "psychological flexibility" (Kashdan & Rottenberg, 2010), "expressive flexibility" (Westphal et al., 2010), "coping flexibility" (Cheng et al., 2014), or "emotion regulation flexibility" (Aldao et al., 2015). For example, the Flex 3 model (Hollenstein, 2015) differentiates dynamic from reactive flexibility. Dynamic flexibility is defined as "moment-to-moment changes in affect within a given context" (Hollenstein, 2015). It requires the inhibition of the current state (negative feedback) and the activation of a subsequent state (positive feedback), reflecting adaptive regulation. Greater propensity for these transitions indicates flexibility, while lower propensity indicates rigidity. Reactive flexibility, at a slightly longer time scale, involves responses to shifts in environmental demands, such as changes in affective content and patterns in different contexts. An example is the shift from negative to positive affect after conflict resolution. Inevitably, Holenstein (2015) argues that the separation of emotion from emotion regulation is impossible. Different measures of flexibility exist, from neuropsychological tasks (Miyake et al., 2000), to questionnaires (Gabrys et al., 2018) and physiological measures (Madison, 2021). All definitions, frameworks, and measures have important contributions for resilience and mental health, and should, thus, be integrated for a more comprehensive understanding of how they enable individuals to respond physiologically, emotionally, cognitively, and behaviorally to stressful situations.

Our research team (Philippot et al., *in prep.*) has worked extensively on providing an exhaustive framework for *psychological* flexibility. It integrates research and theories from the neuropsychology (Diamond, 2013; Miyake et al., 2000), emotion and coping regulation (Aldao et al., 2015), and goal- and self-regulation fields (Bonanno et al., 2023; Bonanno & Burton, 2013). In the context of clinical psychology, we define this concept as an emergent quality of a system, arising from the interplay of different processes that help individuals pursue actions aligned with their values, roles, or goals (Philippot et al., *in prep.*). The model proposes several steps including (1) goal selection, (2) accessing or generating different action repertoires, (3) selecting and (4) implementing the most appropriate strategy, (5) monitoring its effectiveness in reaching the goal, and (6) changing goals and/or strategies (Philippot et al., *in prep.*). The current thesis integrates stages 2 to 5 of this model, highlighting connections between flexibility, as measured in neuropsychology, and its relationship with the development and implementation of various emotion regulation and coping strategies. Although developed for clinical research and work, this model also aligns with some resilience models, which I present in a subsequent section. To conclude, the results obtained from this PhD thesis are encouraging and attest for the relevance of pursuing research on flexibility, specifically.

7.4. Affective vs. Neutral Material

A question that arose as we conducted the thesis studies was the extent to which accounting for the treatment of emotional, rather than neutral stimuli may be more relevant for affect regulation and subsequent stress responses. A different perspective on executive functioning highlights a unified model, concentrating on the *functions* and *processes* that govern behavior (Baggetta & Alexander, 2016). The "hot" and "cool" executive functions model proposes that executive functioning varies along a continuum with two dimensions: a cognitive control dimension (*i.e.*, "cool" executive functioning, relying on neural networks involving lateral parts of the prefrontal cortex; Zelazo, 2020) and an emotion control/regulation dimension (*i.e.*, "hot" executive functioning, needed in motivationally-salient situations and relying on neural networks involving ventral and medial parts of the prefrontal cortex; Zelazo, 2020; Zelazo et al., 1997; Zelazo & Carlson, 2012). Cognitive control over emotional material, therefore, may recruit different processes than general executive functioning.

Given that the ability to manage emotions flexibly is essential for daily life and interpersonal interactions (e.g., Pessoa, 2008), recent research has started to differentiate between purely cognitive flexibility and affective flexibility (Kraft et al., 2020). The theoretical basis of this question lies on the fact that the cognitive control of *emotional* content (i.e., affective flexibility) may be more closely linked to emotion regulation rather than general executive functioning processes per se (Genet et al., 2013; Malooly et al., 2013). In previous research using the affective flexibility task, it was found that the task measured a unique construct with discriminative validity from nonaffective cognitive flexibility (e.g., the Number-Letter task; Malooly et al., 2013). Cognitive flexibility tasks using emotional material have proven to be equally (Genet & Siemer, 2011), if not more relevant (Rademacher et al., 2023), than neutral tasks in predicting emotion regulation and resilience.

Although the implemented designs in this thesis did not allow us to compare results from neutral- and emotional-specific tasks, we did replicate findings implemented in earlier PhD Chapters. In all studies, different indices of affective flexibility were significant predictors of acute stress and affect regulation. They had also been reported for anxiety and resilience (see Chapter 6 for an overview). As discussed in Chapter 6, however, further work is required to understand why this may be, and which may be most relevant in the context of stress responses. As mentioned in the section above, theoretical considerations suggest that some processes underlying psychological flexibility may be context-specific (Braem & Egner, 2018) or related to an individual's superordinate goals (Doebel, 2019). These factors were not accounted for in the present work and could be explored in future studies. Moving forward, research on stress should incorporate designs allowing for direct comparisons between tasks using neutral and affective stimuli.

7.5. Experimental Manipulation of Executive Functioning

A number of effects were found for executive functioning depending on the context under consideration: anticipatory stress, acute laboratory stress, or daily stress. While an experimental manipulation of stress was implemented in Chapter 4, a major limitation of the current thesis is the absence of experimental manipulations of executive functioning. It is important to note, however, that an intervention study was conducted as the last study of the thesis. The results were relatively limited, which is why I describe the findings and implications briefly. The aim of this pilot study was (a) to evaluate the extent to which a cognitive control training improved overall stress levels and (b) to determine, experimentally, which mechanisms may be involved, such as appraisals and affect regulation in real time. To facilitate the observation of clinically meaningful changes for participants in everyday life, a single-case experimental design (SCED) was implemented. The study procedure was approved by the Ethics Commission of the Institute for Research in the Psychological Sciences (UCLouvain).

Single Case Experimental Designs

SCED designs are typically implemented in early developmental phases of intervention development, as practical complements to larger *N* designs (Krasny-Pacini & Evans, 2018). The reasoning behind this choice was to pilot a novel intervention on a small number of patients. A multiple baseline design was selected, where the intervention is introduced sequentially to different participants. These designs demonstrate that change occurs only when the intervention is directed at the participant, setting, or behavior (Krasny-Pacini & Evans, 2018. By eliminating the need to return to baseline, multiple baseline designs are particularly effective for assessing interventions with long-lasting effects (Krasny-Pacini & Evans, 2018). In this context, participants are usually sent repeated outcome measures first during a baseline phase (with no intervention), then during the intervention itself. Here, we applied a sequential (randomized) introduction to the intervention and applied method-specific data analysis, namely visual analyses and meta-analyses. It is important to note that SCEDs are not mere case reports; rather, they are carefully planned studies that precede larger-scale interventions. By introducing an intervention to different groups at different times, we can assess its effectiveness more accurately. If each group begins to show improvements in executive functioning and stress outcomes shortly after starting the intervention—regardless of when that happens—this would suggest that the training is responsible for the observed improvements.

Working Memory Training: A Pilot Study

Study Presentation

The study recruited five women with an average age of 23.80 years (*SD* = 1.50) and 16.20 years of education (*SD* = 1.73). They were not under treatment for diagnosed psychological or neurological disorders and had access to a computer for completing the home-based cognitive training. The cognitive training was based on the work of Hoorelbeke and colleagues (2015, 2016) and consisted of the Paced Auditory Serial Addition Test (PASAT; Tombaugh, 2006). This cognitive training was selected as working memory capacity was a clear candidate facet that emerged from the systematic literature review and meta-analysis (Chapter 2). Moreover, as most tasks that involve executive functioning operate within working memory, a training focused on this facet could maximize transfer gains across different executive functions. The training had previously been implemented in the context of stress research and was feasible in everyday life (Hoorelbeke et al., 2015). Finally, we strived to integrate ecological momentary assessment designs and methodologies within the intervention. This allowed us to apply statistical methods (i.e., meta-analyses) despite the low number of participants.

Regarding the training itself, participants heard a sequence of single-digit numbers (1-9) presented at a constant pace and were asked to mentally sum the last two digits only. Participants then selected the calculated sum from a circle of numbers ranging from 1 to 18 onscreen. The speed at which numbers are presented adapted to the participant's performance, making the training adaptive. They were asked to complete 10 sessions over two weeks from their home computer, with a maximum of 1 session per day.

At pre-test and post-test in the laboratory, participants completed several questionnaires on Qualtrics (Provo, UT) evaluating socioeconomic questions (age, gender, years of education), depression (Center for Epidemiologic Studies Depression Scale; Fuhrer & Rouillon, 1989; Lewinsohn et al., 1997), anxiety (General Anxiety Disorder-7 (Micoulaud-Franchi et al., 2016; Spitzer et al., 2006), chronic stress (Bellinghausen et al., 2009; Cohen et al., 1994), worry (Gosselin et al., 2001), and cognitive emotion regulation (CERQ; Garnefski & Kraaij, 2007; Jermann et al., 2006). They then completed the same four executive functioning tasks administered throughout the studies of this PhD thesis [inhibition (Stop Signal Reaction Time Task, Verbruggen et al., 2019), cognitive flexibility (Number-Letter Task, Miyake et al., 2000), updating (Letter Updating Task, Friedman et al., 2008), and working memory capacity (Operation Span Task, Conway et al., 2005)]. Additionally, continuous measures of heart rate were collected to measure stress changes before and after the training.

During both the baseline and intervention phases, all participants completed daily measures of emotions, stress, and stressful events from the m-Path application (Mestdagh et al., 2022) on their phone. The protocol was very similar to that described in Chapter 5. It consisted of measuring (1) their self-reported emotions (tension, anger, nervousness, hostility, depressed, sad, happy, joyful, relaxed, stressed) and stress (Perceived Stress Scale – 4 items; Cohen et al., 1983) at the current moment, (2) whether a stressful event occurred since the last notification (and information regarding it), and (3) the degree of implementation of a selection of affect regulation strategies to deal with the most important and negative event that occurred that day. We randomly assigned five participants to group A (one-week baseline; two participants), group B (two-week baseline; two participants) or group C (three-week baseline; one participant).

Intervention Results and Discussion

The results for the intervention were limited, both relating to the pre-post measures and daily changes. With respect to executive functioning, one person showed improvements in cognitive flexibility and working memory capacity, while another presented a decrease in cognitive flexibility and an improvement in working memory capacity. Moreover, the reliable change index was calculated to evaluate the presence or absence of a reliable change in the pre-and post-intervention measures (Jacobson & Truax, 1991). We found clinical change in chronic stress levels for two participants. Two participants showed a clinical increase in worry, and one showed a clinical decrease on the same measure. There were no effects for rumination, acceptance, planning, or reappraisal, as measured using the CERQ.

In terms of the daily ecological momentary assessment measures, there was a trend reduction in daily stress and for rumination for one person only, while two individuals showed non-significant reductions in both these constructs. Overall, the meta-analysis for stress (Ruscio's A = -0.40 [0.25-0.57], p =.267) and rumination (Ruscio's A = 0.46 [0.36-0.82], p =.372) were not significant. The results provided no evidence for a significant effect of the intervention upon daily stress. Despite some significant trend decreases found for specific affect regulation strategies, they were often limited to one person only. We found that the meta-analysis for active coping (i.e., "action") approached significance, with values increasing throughout the intervention. However, none of the meta-analyses conducted for the affect regulation strategies were significant.

A series of limitations were observed, which could explain these findings. We provided participants with the opportunity to give feedback on the intervention. Overall, the training was mostly perceived as long, difficult, and frustrating, which may have imposed additional stress on the participants and severely limited participation and motivation for the intervention. Besides a last-minute opt-out before the actual intervention began, all other participants nonetheless completed the entire program. However, perception of cognitive training efficacy has been identified as the most significant predictor of the willingness to invest time in intervention training (Harrell et al., 2019), showing that motivation is particularly important when designing interventions. Additionally, the sample consisted entirely of students. The post-test sessions were conducted during the student revision period, ahead of their university exams. It may be that participants were significantly stressed by the upcoming examinations, increasing post-training stress. An absence of effect for stress may, alternatively, be also indicative that the intervention had a buffering effect against stress. Researchers should work towards replicating these findings and those obtained by Hoorelbeke (2015, 2016) at other timepoints (i.e., not necessarily ahead of the particular period that characterizes university examinations), as well as on other populations.

Furthermore, the study consisted of only ten training sessions. One might question whether this is sufficient to perceive significant results (for discussions, see Denkinger et al., 2021; Jacoby & Ahissar, 2013). Similarly, the main target of this intervention was working memory capacity. However, the results in this thesis highlighted the impact of inhibition and cognitive flexibility, indicating that perhaps that tasks targeting other facets and/or a combination of these may be more appropriate in seeing transfer effects to stress and affect regulation.

Finally, there is a considerable limitation in the use of a one-week baseline to conduct a meta-analysis. A power analysis conducted using the *SCED* package in R (Ianhussey, 2022) after data collection indicated that a minimum of 15 weeks of baseline and of intervention are required to run meta-analyses. Moreover, it would be interesting to conduct an additional "baseline" collection after the end of the intervention, to avoid intervention effects on daily measures. It is possible that the reduction in stress was visible after the intervention, but that this was not captured in daily life by the ecological momentary assessment design. We encourage researchers to continue their efforts, as, at the individual level, we did see some trends and effects. A clearer understanding of what these executive functioning tasks measure is warranted, as we will see in the limitations and perspectives section.

7.6. Implications for Research and Practice

Regarding the practical implications of this thesis, a few recommendations could be made. In this section, I discuss the findings from existing cognitive interventions, as well as the implications for both executive functioning and affect regulation training. As a reminder, the systematic review and meta-analysis (Chapter 2) found that there is very limited work on interventions targeting executive functioning for stress regulation, with attention and working memory interventions having been developed. The review found that while attentional training did not significantly impact stress reactivity, it did facilitate faster HRV recovery, indicating a potential for improved adaptability. Particularly noteworthy were findings regarding updating and reactivity, where training in working memory updating led to reduced cortisol reactivity among individuals with higher rumination tendencies. This underscores the importance of modifying attentional focus away from threatening material towards positive information for achieving homeostasis. Additionally, attentional processes may play a crucial role in regulating physiological return to baseline and limiting sustained stress system activation, as evidenced by attention bias modification's (ABM) promising long-term effects on habituation to repeated stressors. However, the efficacy of ABM as a primary treatment for anxiety disorders remains uncertain, and while stress and anxiety processes differ, caution is warranted when applying paradigms from clinical psychology to stress research. Moreover, there is no evidence for the efficacy of training focused on cognitive flexibility or inhibition, specifically, upon stress. This remains an important area of potential research.

To facilitate the elucidation of the role of distinct executive functions, based on the designs implemented in this thesis, one could imagine participants being randomly assigned to six intervention groups: an inhibition-only, cognitive flexibility-only, updating-only, working memory-only, combined executive functioning training, and control group. Independent manipulations of distinct executive functioning facets in this manner, coupled with a pre- and post-test session, as well as daily measures of stress outcomes, could enable researchers to understand which facet to focus on for promoting adaptive stress responses and regulation. The feasibility of this project is complexified by the costs that such a design implies, yet it would be ideal for providing a clearer message regarding the directionality of the executive functioning-stress association.

Beyond traditional executive functioning computer-based training in the laboratory, researchers also insist on improving the motivational salience of the training. Implementing gaming elements and social interactions may improve the interest and motivation of participants for such interventions (Belleville et al., 2023). A psychoeducation module addressing the relevance of the training for the participants' difficulties is also imperative.

Finally, accessibility is another key factor of executive functioning training. Ecological momentary assessment designs offer the possibility for easily implementable daily practices of executive functioning training. For example, the m-Path application implemented in Chapter 5 and in the interventional study can facilitate the scheduling and implementation of real-time therapeutic exercises, assignments, or reminders, allowing researchers to assess their effectiveness immediately (Mestdagh et al., 2022). Researchers can review summaries presented through timelines, charts, and graphs for each participant or patient. This feedback tool empowers practitioners to evaluate and adjust therapy goals in real time, facilitating meaningful discussions with clients during therapy sessions. While the development of such practices in real-life is still in progress, there is real potential for promoting daily cognitive training through these devices.

In terms of real-life practical and clinical implementations for executive functioning training, cognitive control training methods are already being integrated into specific therapeutic approaches, like those used in Wells and Matthews' (1996) metacognitive therapy for anxiety and depression. While these have been developed as attentional training, specifically, practitioners should consider similar implementations for improving set-shifting and cognitive flexibility. Based on a more comprehensive approach to flexibility (Philippot et al., *in prep.*), clinicians or mental health professionals could develop interventions and/or workshops focusing on fostering flexibility in affect regulation. This could involve helping participants to generate different affect regulation strategies (i.e. expanding the repertoire of possible strategies) and educating them on the importance of selecting adaptive strategies tailored to specific stressors and contexts. Moreover, individuals or patients should be taught to recognize and to disengage from nonadaptive strategies that prove to be ineffective or detrimental in specific contexts. By enabling individuals to better regulate their daily stress responses, these tailored interventions could help minimize repeated and often unnecessary stress activation from daily stressors.

7.7. Strengths, Limitations, and Perspectives

Thesis Strengths

Before addressing the limitations and future directions of this study, it is important to highlight several strengths of this thesis not otherwise mentioned in this General Discussion. This thesis consistently examines the role of executive functioning across various stress contexts, beginning with the first systematic literature review and meta-analysis focused on this specific association. The PhD studies were varied in terms of providing different types of stressors, including evaluative stressor (i.e., university examinations; Chapters 3 and 6), psychosocial and physical stressor (Chapters 4 and 6) and daily stressors (Chapter 5). This multidimensional approach to both executive functioning and stress provided nuanced insights into their relationship. Rather than focusing on a global executive functioning score, we strived to account the particularities and variance of different executive functioning facets. This is particularly evident as most significant effects in the laboratory study (Chapter 4) disappeared when all facets were combined into a single global cognitive score.

Additionally, we identified sources of variance and bias in all statistical models, adjusting for model assumptions, outliers, and relevant covariates. Importantly, all studies were pre-registered, either on Prospero (Chapter 2; https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=122297), as a peer-reviewed pre-registered report in Psychophysiology (Chapter 4), or on the Open Science Framework (Chapters 3-6; www.osf.io). We adopted a completely transparent approach to our hypotheses and analyses, clearly indicating when analyses were exploratory. This transparency aims to enhance the reproducibility of our findings by other research teams.

Thesis Limitations and Research Perspectives

Despite the interesting findings, the majority of our samples consisted of mostly young and healthy adults recruited from Louvain-La-Neuve in Belgium. Most studies required participants to attend the UCLouvain Psychology Faculty. This sample represents a very limited sample of the Belgian population, let alone world-wide. It is important that other researchers replicate these results in other populations. Alongside implementing a cognitive training, researchers should thoroughly consider the populations that may benefit the most from these interventions. We had selected participants based on chronic stress levels, but other options may be looking at populations with specific cognitive deficits, as these may also be generated by chronic stress. Moreover, the results give us a snapshot of the associations between executive functioning and stress responses in healthy populations. However, this association may also vary in populations that are vulnerable to stress. For example, there are a number of stress-related disorders, including anxiety, depression, burnout, post-traumatic stress disorder, or even adaptation syndrome. Chronic stress may result in continuously engaging limited cognitive resources, which may, in turn, lead to more difficult affect regulation (Gabrys et al., 2018; McEwen, 2003). Under these circumstances, perhaps executive functioning may be even more relevant for protecting against stress-related symptoms and long-term physiological damage.

Executive Functioning Measurement

Executive functioning was measured using the same executive functioning tasks throughout the studies. While this is a cross-sectional strength of the PhD, it also limits the findings to these specific tasks and to Miyake and colleagues' Unity/diversity framework (Friedman et al., 2008; Friedman & Miyake, 2017; Miyake et al., 2000; Miyake & Friedman, 2012). There are numerous other executive functioning tasks and frameworks (Baggetta & Alexander, 2016) that could, and should, be investigated. Similarly, existing research indicates that core executive functions are distinct but highly interconnected constructs (Miyake et al., 2000). As a result, isolating these functions from one another is challenging, as they often depend on each other (Kupis & Uddin, 2023). For instance, many flexibility tasks require working memory to retain task rules and inhibition to avoid repeating previous responses.

This task "impurity" problem is not new (Baggetta & Alexander, 2016). Implementing multiple tasks of different executive functioning facets could aid in providing more complete measures of each component of executive functioning. Furthermore, there is evidence of distinctive brain regions being activated exclusively during cognitive flexibility tasks, while other regions are activated across a broader range of executive function tasks (Rodríguez-Nieto et al., 2022). Specific to cognitive flexibility, this thesis was not approached from a neurological point of view, though, as previously discussed both in this thesis and in the literature (e.g., Kalisch et al., 2017), accompanying neural measures of executive functioning, affect regulation, and stress physiology could bring tremendous information regarding these interconnected processes.

While we do find a significant impact of executive functioning, the nature of the material being treated by these functions remains unclear. Previous frameworks mention that the material treated by executive functioning relates to relevant goals (Crum et al., 2020; Hofmann et al., 2012; Pruessner et al., 2020; Schmeichel & Tang, 2015). Here, the cognitive tasks administered to the participants did not tap specific stimuli or information regarding ecological goals in the eye of the participant. Thus, while we find evidence for a general effect of executive functioning relating to neutral information, future research should also focus on developing tasks that target goals that are motivationally salient for the participant.

Moreover, we considered executive functioning only at baseline, viewing these as potentially stable characteristics over time (Ettenhofer et al., 2006; Gabrys et al., 2018). However, executive functioning can also be studied in its *daily fluctuations*, as proposed by new ecological momentary assessment approaches (e.g., Benson et al., 2023; Rónai et al., 2024). Measures of intraindividual variability have been proposed as a transdiagnostic biomarker of cognitive functioning for a number of medical conditions, including Multiple Sclerosis, Parkinson's Disease, or Dementia (for a review, see McKinney et al., 2020). Future work could work on integrating these momentary assessments of executive functioning within the proposed PhD framework.

Lastly, in this thesis, executive functioning was only tested in non-stressful situations. Yet, studies of animals show that stress can remodel brain structure and function (McEwen, 2012). By potentially restricting projections to the prefrontal cortex, stress responses may focus and maintain attentional processes on the specific stressor, and limit switching to stressor-irrelevant information (Gee & Casey, 2015). Evaluating these functions under stress might be more relevant, reflecting real-life scenarios where individuals face acute stressors. Executive functioning *under stress* may better represent the resources available to individuals when they are stressed. Therefore, researchers should design studies to test executive functioning under both non-stressful and stressful circumstances. One could then compare the two scores and relate them to acute stress responses. For example, Shields and colleagues (2017) found that executive functioning moderated the link between recent exposure to stress and health complains. Enhanced executive functioning under acute stress, but not in non-stressful conditions, was associated with a reduced association between the two variables. Nonetheless, the reversibility of stress effects also varies by brain region. Evidence suggests that the hippocampus and prefrontal cortex have a greater capacity for change or plasticity after stress, with many effects being reversible once stress ends (Gee & Casey, 2015; Liston et al., 2009). Should researchers develop interventions focused on manipulating executive functioning, they should be adapted according to different stress conditions to maximize training potential and transfer effects to stress regulation in everyday life.

Stress Measurement

Stress Metrics: Physiological and Psychological Indices. This thesis attempted to capture stress responses across a number of designs and measurements, incorporating both physiological and psychological stress indexes. However, it is obvious that not all possible stress scenarios were accounted for, leaving much room for replicability and adaptation to other settings. For example, a stressor may be considered as either physical, psychological, or both (Godoy et al., 2018). Physical and psychosocial stressors may activate different neural regions depending on the type of threat (Moses et al., 2023; Noack et al., 2019). We chose a specific stress induction in the laboratory while many others exist (for reviews, please see Ernst et al., 2023; Moses et al., 2023; Skoluda et al., 2015). Additionally, due to budget limitations, we did not implement physiological measures across all studies. It is important to note that inconsistencies in biobehavioral responses to stressors have nonetheless been reported across different contexts (Giles et al., 2014). Finally, a final consideration for stress responses is examining habituation. This is defined as the adaptive ability of attenuating the physiological stress response when being repeatedly exposed to the same (or different) stressor(s) (Quaedflieg et al., 2017). Thus, the results of the current thesis provide only a snapshot of the vast domain that is devoted to stress research. Pursuing research efforts across different stressful conditions and applying varied stress measurements may bring to light more information about the generalizability of the current PhD thesis results, and why they may exist.

The Paradox of Stress: When Is It Good or Bad? An additional question raised by this PhD thesis is understanding what "good" or "bad" stress responses look like. Physiological responses to stressors can enhance survival and safety, but they can also have negative psychobiological effects and contribute to the onset and maintenance of psychiatric disorders and disease (Epel et al., 2018; Lupien et al., 2018). Chronic activation of the limbic-HPA axis or persistence of stress-related physiological activity despite the absence of an acute stressor can lead to the deterioration of frontolimbic circuitry (Gee & Casey, 2015). Most studies in the literature have focused on the linear relationship between stress reactivity and health, where lower levels of reactivity would be associated with better health (Rush et al., 2024). Therefore, this thesis rested on the postulate that excessive reactivity was necessarily bad for one's health.

However, how does one define a response as "excessive" in the case of acute stressors? Blunted stress responses to acute stressors are also considered unhealthy and maladaptive, characteristic of a number of clinical conditions (e.g., depression, panic disorder, and eating disorders; Burke et al., 2005; Petrowski et al., 2013; Vaz-Leal et al., 2018). Low reactivity may be indicative of the implementation of coping strategies that involves disengaging from or minimizing the impact of stressors, which can be adaptive in the short term but potentially maladaptive in the long term (Carver et al., 1989).

Hormetic models and research on stress inoculation propose that some level of adversity may be more beneficial for psychological and physical functioning, compared to no adversity or severe adversity (e.g., Meichenbaum, 1993). Research on both primates and humans suggests that moderate stress exposure and responses yields a certain degree of benefits, including increased prefrontal volume and function (e.g., Parker et al., 2005). Moderate stress early in life has been associated with reduced cortisol reactivity to acute stressors (e.g., Hagan et al., 2014). Experiencing mild levels of life adversities may offer psychological benefits, such as increased resilience, self-efficacy, and personal growth (Seery et al., 2010; Seery & Quinton, 2016). Hence, a more nuanced approach to the study of stress would be that stress responses vary along a continuum, where both ends of the stress exposure and reactivity (i.e., no stress at all and extreme stress reactivity) are neither optimal for one's health.

Exposure to a moderate amount of lifetime adversity is also associated with better mental health and improved responses to *daily* stressors (Rush et al., 2024). In a daily diary study, Rush and colleagues (2024) found significant quadratic effects for stress reactivity on well-being. Relative to low or high stress reactivity, moderate levels of reactivity were associated with higher life satisfaction, lower psychological distress, and lower numbers of chronic conditions. The observed benefits, therefore, might depend more on individuals' stress responses to daily stressors rather than the number of stressors they encounter per se.

Going forward, I encourage stress researchers to move past traditional and linear operationalizations of stress exposure and reactivity. Efforts could be conducted towards evaluating ranges of "cut-offs" for the "appropriate" amount of stress reactivity (Rush et al., 2024). Although this promises to be a complicated endeavor, it may aid in designing interventions for stress reactivity, as well as in evaluating their efficacy. As suggested by Rush and colleagues (2024), individuals with low stress reactivity could benefit from emotion awareness and expression training using mindfulness-based therapies, while individuals with high reactivity could work at reducing emotional arousal and distress, through cognitive-behavioral therapy or relaxation training. Researchers should also implement quadratic analyses to capture stress affect and its intricate relationship with executive functioning. More complex statistical methods, such as piecewise latent growth models (Degering et al., 2023; Lopez-Duran et al., 2014), could provide more fine-tuned calculations of stress reactivity and recovery to stressors, especially in the laboratory. Similar conceptual and methodology work undertaken in ecological momentary assessment studies (De Calheiros Velozo et al., 2023; Smyth et al., 2023) should persevere to help clarify how one can best capture reactivity and recovery using such designs. By embracing these advanced approaches, researchers could gain a deeper understanding of the multifaceted nature of stress and its implications for mental health and well-being.

Understanding Resilience Through Stress Responses. A final research avenue linked to promoting healthy stress responses is the field of resilience. Various conceptualizations and operationalizations of resilience have been proposed (for reviews, see Arnold et al., 2023; Kalisch et al., 2017), described generally as a dynamic process that should be assessed within a temporal context (Ong & Leger, 2022). It refers to the ability to (a) recover from stress-related damage (e.g., to a potentially traumatic event) and (b) to adapt to changes in the environment (McEwen, 2012). Thus, resilience may be understood as how one adapts to stressors in daily life.

Exposure to a moderate amount of adversity could contribute to reinforcing this resilience in individuals (Rush et al., 2024). In their review, Arnold and colleagues (2023) detail the different definitions of resilience as (a) a trait and capacity, (b) an outcome, and (c) a dynamic process. The first, however, has been contested, with prominent theories insisting on resilience as a process (Kalisch et al., 2017). Figure 24 illustrates these outcome and dynamic approaches to resilience, incorporating the importance of how one responds to acute stressors. The black line across all three images illustrates how one may be resilient throughout single, repeated, or long-lasting stressors (i.e., as an outcome). Resilience, in the context of daily stressors, would be characterized by the presence of a stress reactivity response followed by a recovery process (Figures 24a and 24b), as well as a habituation to the sustained exposure to the stressor (i.e., dynamic process). To capture these processes, the authors encourage the use of measurement burst designs in ecological momentary assessment designs with short time lags (e.g., one-week daily diary study) over repeated intervals (e.g., with several months between bursts; Stawski et al., 2008).

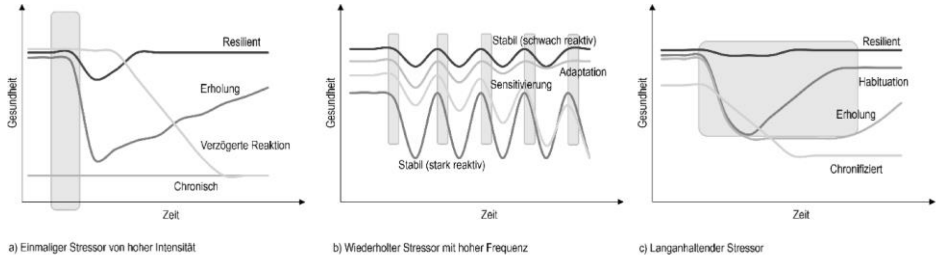

Figure 24. Measurement of Resilience as a Dynamic Process

Note. Figure copied, with permission from the authors, from Arnold and colleagues (2023).

Meanwhile, Ong and Leger (2022) propose a framework for resilience within the Intraindividual Variability and Change framework, comprising sustainability, recovery, and steeling. Sustainability involves maintaining one's well-being during and after major life stressors (Bonanno, 2004; Masten et al., 1990). Recovery refers to the rapid and effective return to stability after facing adversity (Curtis & Cicchetti, 2003; Davidson, 2000). Steeling is the process by which past exposure to stressors strengthens coping abilities for future challenges (Rutter, 2012; Seery, 2011). This dynamic perspective highlights the significance of even minor daily life events in resilience research. The authors suggest that resilience is characterized by dampened reactivity, rapid recovery, moderate stressor exposure, and high stressor diversity. Reactivity, in this context, is defined as intra-individual variations in the association between daily stress exposure and affect (Sin et al., 2015). From a resilience standpoint, individual-level parameters represent a spectrum of reactivity to daily stressors, ranging from *resilience* (reduced reactivity) to *vulnerability* (heightened reactivity). Furthermore, Ong and Leger (2022) advocate for integrating lifespan principles into resilience research, questioning the timing, direction, and rate of change in resilience processes before and after exposure to adversity. They emphasize the importance of integrating *plasticity* (adaptive potential, Staudinger et al.,

1993) and *reserve capacity* (the capacity to maintain functionality after a stressor, Cullati et al., 2018). While previous research has primarily focused on evaluating stress experiences at specific time points, lifespan perspectives, such as this one, offer valuable insights into how resilience develops over the course of life. Prospective, longitudinal studies combining repeated measurements of executive functioning tasks and ecological momentary assessment measurement bursts designs present promising avenues for future research.

Though resilience was not a variable of the initial PhD thesis proposal, I see it as a crucial aspect for future research on acute stress. It seems essential to examine stress responses over a broader time scale rather than at isolated moments. Resilience research also aims to understand why individuals do or do not develop stress-related disorders following adversity (Kalisch et al., 2017). Therefore, identifying how facets of executive functioning may be implicated in acute stressors could also help in protecting individuals from the more long-term negative impacts of stress, with an important influence for public health. Ultimately, understanding these dynamics could inform health promotion initiatives and preventive mental health interventions. Given that comprehensive resilience frameworks are still relatively new (Arnold et al., 2023; Ong & Leger, 2022), there is substantial potential for further advancement in this research area in the coming years.

Affect Regulation Measurement

While it is very interesting to notice associations between neuropsychological tasks and affect regulation strategies, a limitation of this thesis is that our design does not give information on *how* executive functioning is involved in affect regulation. A final model for the understanding of neurocognitive processes is Braver's (2012) Dual Mechanisms of Control Framework. It distinguishes between proactive and reactive modes of control. The former occurs before encountering a stimulus and involves preparatory processes that enhance coping with conflict or challenge upon presentation. This mode reflects the sustained and anticipatory maintenance of goal-relevant information in the dorsolateral prefrontal cortex to optimize cognitive performance. In contrast, reactive control acts as a corrective mechanism, recruiting processing resources to resolve conflict once one is confronted to it.

Building on this model, the Neurocognitive Framework for Regulation Expectation (De Raedt & Hooley, 2016; Nasso et al., 2020) proposes that individuals may be anticipating their abilities to cope with stressors before encountering a stressful situation. Such anticipation may include proactive up- or downregulation of specific neurocircuits before the actual encounter with the stressful event occurs, influencing subsequent actual regulatory responses. Therefore, expectations, such as appraisals, regarding impending stressful events may shape subsequent coping responses, leading to potential adaptive or maladaptive outcomes for the individual.

The interconnection between appraisals and affect regulation were not investigated in this thesis, notably due to statistical power limitations. Now that we have preliminary evidence of links between executive functioning, stress regulation, and stress affect, future research attempting to validate the entire theoretical framework at once (Figure 22) should recruit important sample sizes to run structural equation models that account for all variables and interactions at once in one study.

Finally, it is important to acknowledge that although we investigated the links between affect regulation variability and flexibility, there are a number of other ways to investigate affect regulation. For example, researchers (e.g., Pierce et al., 2022) have proposed to run latent profile analyses in emotion regulation strategies to investigate how these patterns relate to various clinical disorders. Other researchers discuss the use of affect regulation competencies and its efficiency, as well as the investigation of affect regulation in the context of both positive and negative emotions. There is also important recognition that the implementation of affect regulation must be synchronized with contextual demands.

A remaining avenue of research in this domain is also accounting for this dynamic nature of affect regulation flexibility (English & Eldesouky, 2020). This involves examining the contextual features that co-vary alongside fluctuations in affect regulation strategy use. While we did obtain some degree of stressor-related contextual information in Chapters 3 (examination stress), 4 (laboratory stress) and 6 (examination and laboratory stress), this is an important limitation of Chapter 5 (daily stress). We did not collect information regarding the surroundings of the person at each reported stressor, though we did measure internal characteristics, such as stressor types and appraisals (Greenway et al., 2018). A major methodological question for researchers this field is how one may measure these contextual demands, as well as the different indices of affect regulation flexibility. Finally, accounting for personal goals would also aid in understanding the regulation goal behind the implemented strategy (Bonanno & Burton, 2013).

Conclusion

This PhD project aligned with recent research perspectives that view executive functioning as a protective factor for mental and physical health, resilience, and subjective and physiological responses to acute stressors. The objectives of this PhD thesis were two-fold. First, it examined how various facets of executive functioning (inhibition, cognitive flexibility, updating, and working memory capacity) protect against acute stress responses (anticipation, reactivity, and recovery). Second, it explored the mediating role of cognitive and behavioral processes in the association between executive functioning and stress responses, namely cognitive stress appraisals and affect regulation strategies. This thesis aimed to overcome previous research limitations through a multidimensional approach to executive functioning and stress responses. It also prioritized transparency and replicability by investigating these associations across controlled and ecological contexts, including examination stress in university students, laboratory-induced stressors, and daily stressors through an ecological momentary assessment design.

Overall, better inhibition, cognitive flexibility, and working memory capacity were associated with lower anticipation and reactivity, as well as more adaptive recovery from stressors. Across all studies, we found evidence linking cognitive flexibility, updating, and working memory capacity to the strategies used to regulate one's affect. Inhibition and cognitive flexibility were also associated with variability in the implemented affect regulation strategies. However, most of our initial hypotheses were not confirmed, with unexpected results emerging, sometimes even contradicting our pre-registered hypotheses. There was also limited evidence for executive functioning predicting cognitive appraisals ahead of stressors. Additionally, we explored the role of affective flexibility in stress regulation and found significant effects of switch costs on both stress responses and affect regulation strategies.

Moving forward, we emphasize the need replication across different stress contexts to determine which facets of executive functioning are consistently involved in stress regulation. We also advocate for the integration of neurobiological hypotheses and theories to understand the origins of the association between executive functioning, stress responses, and stress regulation. This thesis suggests the critical role of cognitive flexibility in stress regulation, joining the call for an overarching model of flexibility. Future research should actively integrate cognitive and affective flexibility tasks to differentiate general from emotion-specific effects. Once the theoretical and neurobiological foundations are elucidated, we advocate for the development of interventions targeting both cognitive flexibility and flexibility in affect regulation strategies to promote adaptive stress responses to acute stressors in everyday life.

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Appendices

Appendix A:
Grimm et al. (2024)

Stress Appraisal Measure: Investigating the Factor Structure and Validity in the French Language

The Stress Appraisal Measure (SAM, Peacock & Wong, 1990) captures six different types of cognitive appraisals in anticipation of an upcoming stressful situation. The goal of this article was to examine the factorial structure and the validity of the scale in the French language while accounting for existing limitations in the literature. These include factorial structure instability and low internal consistency for specific subscales across multiple validation studies in other languages. In the first study (N = 425), the results from an exploratory factor analysis reliably suggested the removal of five items, the bridging of the threat and challenge subscales as one, and a new general five-factor structure. The new structure and its construct, convergent, and discriminant validity were confirmed in a second study (N = 308). We discuss the relevance of this five-factor scale for the studies focused on individual differences in stress and appraisals.

Reference

Grimm, E., Francia, L., & Agrigoroaei, S. (2024). Stress Appraisal Measure: Investigating the Factor Structure and Validity in the French Language. *Assessment*, 1-20. https://doi.org/10.1177/10731911231223120

A.1 Introduction

Based on the Transactional Model of Stress and Coping (Lazarus & Folkman, 1984), the Stress Appraisal Measure (Peacock & Wong, 1990) provides a multidimensional measurement of cognitive appraisals in anticipation of a stressor. The principal assumption of Lazarus and Folkman's (1984) theory lies upon the fact that stress responses result from an imbalance between one's perception of the situational demands (i.e., primary appraisals) and one's perceived coping options and resources (i.e., secondary appraisals). When exposed to a potentially stressful situation, one proceeds with an initial evaluation of whether "the encounter with the environment is relevant to his or her well-being" (e.g., centrality, Folkman et al., 1986). For the event to be evaluated as stressful, Lazarus and Folkman (1984) suggest the outcome of the event must thus be important for the person.

The individual will also evaluate the event as neutral, positive, or negative (Lazarus & Folkman, 1984). In the first two options, the predicted consequences are perceived as beneficial, and/or resources are not considered to be taxed or exceeded by the situation. If one deems the event negative, however, one may further evaluate it as harmful (i.e., in the case of damage or a loss that has already occurred), threatening (i.e., anticipating harm or loss in an upcoming event), or challenging (i.e., a threat that may be overcome, Carpenter, 2016).

In parallel, the individual will assess one's available coping resources and the extent of realistic possibilities of control over the stressor given the situational demands (Gaab et al., 2005; Lazarus & Folkman, 1984b). Stress, therefore, results from the interaction between these two types of appraisals that can occur simultaneously (Lazarus & Folkman, 1984), The transactional model of stress considers the cognitive appraisals as dynamic processes not only influenced by specific antecedents but also impacting coping choices and outcomes (Newton & McIntosh, 2009). In support of this, associations have been reported between stress appraisals and coping strategies (e.g., Lowe et al., 2003; Yokota et al., 2022). Additionally, appraisals have also been linked with stress-related outcomes, such as daily stressors and life events, and stress-related complications linked to one's mental and/or physical health (Gomes et al., 2013; Webster et al., 2011). For example, Webster and colleagues (2011) revealed that stressors were not only directly associated with outcomes, such as emotional exhaustion, physical symptoms, job dissatisfaction, and turnover intentions, but primary appraisal also mediated these relationships.

The Stress Appraisal Measure

The Stress Appraisal Measure (SAM) was developed by Peacock and Wong (1990) to capture state appraisals concerning an upcoming, predefined stressor. Particularly relevant for ecological situations and grounded in the dimensions of Lazarus and Folkman's transactional stress model (Lazarus & Folkman, 1984), the SAM introduces a comprehensive, multidimensional conceptualization of appraisals. This framework entails three primary appraisal (i.e., evaluation of the importance of an event for one's well-being) subscales, each comprising four items: threat, challenge, and centrality. Centrality is described as an orthogonal concept of both threat and challenge, aiming to assess the personal investment at stake rather than the specifics of the stakes involved.

Moreover, Peacock and Wong (1990) further divide secondary appraisals (i.e., availability of coping resources and controllability of the stressors) into three categories: controllable by oneself, controllable by others, and uncontrollable by anyone. This categorization stems from the recognition that perceptions of control are multi-faceted (Folkman, 1984), and aligns with their study findings, revealing distinct correlation patterns between these subscales and coping strategies (Wong & Reker, 1983). Finally, the scale offers a four-item index of stressfulness (see Table 19 for a full description of each construct as defined by the authors).

Table 19. SAM Subscale Definitions according to Peacock and Wong (1990)

SAM Subscales	Definition	Item Example
Primary Appraisal		
Threat	Perception that one lacks the personal resources to deal with the current situation, seeing oneself in danger of harm or loss.	*Will the outcome of this situation be negative?*
Challenge	Perception that one possesses the personal resources to deal with the current situation, seeing one's own propensity for growth or gains.	*Is this going to have a positive impact on me?*
Centrality	Perception that current situation is central to- and consequential for one's life and personal wellbeing.	*Does this situation have important consequences for me?*
Secondary Appraisal		
Controllable by Self	Perception that one can do something about the current situation.	*Do I have the ability to do well in this situation?*
Controllable by Others	Perception that others can do something about the current situation.	*Is there someone or some agency I can turn to for help if I need it?*
Uncontrollable by Anyone	Perception that no one can do anything about the current situation.	*Is the outcome of this situation uncontrollable by anyone?*
Stressfulness	Overall perceived stressfulness of the situation	*Currently, to what extent does this situation make me anxious?*

Peacock and Wong (1990) developed the SAM in English through three consecutive studies. Study 1 consisted of administering the questionnaire to 100 undergraduate students four weeks prior to their final course examination. The six-factor structure was proposed through a principal component analysis (PCA) with varimax rotation. Study 2 aimed to analyze construct validity in a sample of 154 first-year students, by examining whether the perception of two different stressful scenarios could be differentiated using the SAM. The participants read two stress-inducing scenarios before completing the SAM, namely considering the prospects of (1) "not finding a suitable summer employment" and (2) "being exposed to the virus responsible for AIDS." Study 3 focused on replicating the factor structure (PCA with varimax rotation) and providing convergent validity with respect to measures of locus of control, dysphoric mood, and psychological symptoms. They had 144 first-year students complete the SAM three weeks ahead of the winter university examinations.

Since its creation, the measure has been adapted for adolescents (Rowley et al., 2005), for use in religious contexts (Newton & McIntosh, 2010), and in a dispositional format (i.e., with respect to general stress as opposed to an acute stressor, Roesch & Rowley, 2005; Senol-Durak & Durak, 2012). Validation studies efforts in other languages have been led in French (Pelchat et al., 1995), German (Delahaye et al., 2015), Portuguese (Nazaré & Fonseca, 2021), and Turkish (Durak & Senol-Durak, 2013).

Factor Structure in Different Languages

The six-factor structure, while grounded in theory, demonstrates notable instability, particularly regarding its factor structure across diverse languages like English, French, German, Turkish, and Portuguese. Additionally, lower levels of internal consistency are observed across all languages. In Peacock and Wong's (1990) second study, threat, and centrality loaded onto the same factor. While this was not the case in their third study, one item from challenge (item 7: positive impact) and uncontrollable-by-anyone (item 1: totally hopeless) loaded onto different subscales, while one failed to load entirely (item 3: outcome uncontrollable). The authors suggest this may be due to the low variability observed for the uncontrollable-by-anyone items in Studies 1 and 3.

In the validation study for adolescents, the EFA conducted by Rowley and colleagues (2005) indicated a three-factor solution (i.e., threat, challenge, and resources). The authors propose that the smaller number of factors obtained in adolescents' appraisals results from less complex appraisal structures in contrast to those found in adults. For instance, the absence of the centrality facet is attributed to the belief that it requires a more intricate thinking pattern, which they consider to be still underdeveloped in adolescents.

The problem of factor instability also arises in other language validation studies that applied, for comparison purposes, similar designs (i.e., instructions prior to questionnaire completion) and analyses (i.e., PCA with varimax rotation) to the original study. In a previous French version, Pelchat and colleagues (1995) reported a four- and five-factor structure in Studies 1 and 2, respectively. In Study 1, threat and centrality combined into one factor, while challenge items loaded onto several others. Despite an alteration of the SAM items for Study 2, threat and centrality items continued to load together. Important cross-loadings were observed, leaving the uncontrollable-by-anyone and challenge subscales composed of as little as two items. This outcome was interpreted by Pelchat and colleagues (1995) as stemming from the phrasing of the centrality items. While the

English version concentrated on centrality from an individual's standpoint, Pelchat and colleagues (1995) suggested that rephrasing the items to encompass a wider context—such as the implications of the situation on everyday life and overarching life objectives—might be more fitting. Their latest adaptation in French thus utilized the phrasing "about my life" instead of "for me" and "about me", but these changes remain to be validated.

In the German validation study (Delahaye et al., 2015), a confirmatory factor analysis (CFA) failed to replicate the six-factor structure of the SAM instrument. A subsequent PCA also suggested a five-factor solution, where one factor combined threat and centrality, with two additional items [1 (totally hopeless) and 19 (excited about the outcome)] loading onto it. The challenge subscale comprised two items only. The authors point out the “medium-high scale inter-correlations”, indicating that while the six subscales represent different constructs, it is undeniable that they are related. They do not regard this as evidence contradicting the transactional model; rather, they perceive it as a matter connected to the insufficiency of the proposed number of items per scale to effectively capture these concepts.

With respect to the Turkish state scale validation, the authors conducted a calibration study (Study 1: N = 461 undergraduate students; EFA) and a subsequent validation study for the factor structure obtained in Study 1 (Study 2: 751 university students and 548 adults; CFA; Durak & Senol-Durak, 2013). A five-factor solution was confirmed, where centrality also loaded onto threat. The authors explain their findings in terms of the academic stressor employed in their study; university students may be more inclined to attribute importance to events they deem as threatening. Furthermore, they found that item 7 ("eager-to-tackle") also loaded onto the controllable-by-self factor, which the authors interpret as a reflection of cultural differences between Western and Eastern individuals. In the Turkish context, individuals might have been taught to obey rules and depend on their parents during childhood, leading to a lack of encouragement to be genuinely eager to tackle challenging situations.

In contrast, the CFA conducted for the Portuguese version (Nazaré & Fonseca, 2021) failed to fit adequately with both Durak and Senol-Durak (2013) and Honey and colleagues’ (2003) five-factor structures. Given poor fit indices, the authors respecified Peacock and Wong’s (1990) original model, adding a correlation between items 18 and 21 (both from uncontrollable-by-anyone), and removing correlations between centrality and the secondary appraisals. This modified model reported the best fit indices compared to those tested earlier. However, it is important to note that the authors omitted the uncontrollable-by-anyone subscale, given that the items relating to this scale were poorly suited for the chosen stressor (i.e., participants were asked to “consider the birth of their youngest child”).

Internal Consistency

With respect to internal consistency, the values obtained by Peacock and Wong (1990) for the six subscales vary across studies. The coefficients range from .51 (uncontrollable-by-anyone) to .90 (centrality), from .73 (threat) to .86 (controllable-by-self), and from .57 (uncontrollable-by-anyone) to .84 (centrality/controllable-by-self) in studies 1, 2, and 3, respectively. It is important to note that the Cronbach alpha threshold for acceptable reliability is usually set at .70 (Nunnally & Bernstein, 1994). Carpenter (2016) also reviewed 12 published articles in English, with reliability estimates ranging from .68 to .90.

Unstable, lower internal consistency coefficients are also obtained in the translated versions of the instrument, especially for the challenge subscale. In Pelchat and colleagues' (1995) studies, the coefficients for challenge range from .40 (Study 1) to .60 (Study 2), while for all other subscales, the coefficients range from .71 to .87. Consequently, the authors suggest rephrasing three items (1, 14, 19) but do not conduct further CFA on the updated version. In the German measure, most alphas for the original SAM subscales were above .71, though challenge was also problematic at .57. They further suggested that additional items should be considered to improve the conceptual definitions of primary appraisals. More promisingly, reliability coefficients ranged from .68 (challenge) to .86 (threat and controllable-by-others) in the state version in Turkish (Durak & Senol-Durak, 2013), and from .66 (threat) to .86 (controllable-by-self) in Nazaré and Fonseca (2021)'s modified Portuguese questionnaire for stress appraisals related to childbirth.

Procedural Differences and Item Wording

In addition to the recommendations provided by various authors, the variations in factor structure and internal consistencies could also be attributed to the instructions provided to participants in previous research. To elaborate, in Studies 1 and 3, Peacock and Wong (1990) instructed students to complete their questionnaire ahead of their exams in Studies 1 and 3. However, Study 2 involved randomly assigning participants to two different sets of scenario prompts. One set of instructions required participants to assess the likelihood of not being able to secure suitable summer employment prior to completing the SAM, while the alternative instructions prompted participants to evaluate the probability of encountering the virus responsible for AIDS. Interestingly, despite the lack of relevance to impending exams, the second study revealed the highest levels of internal consistency across all indicators. Both Pelchat and colleagues (1995) and Delahaye and colleagues (2015) instructed college students to complete their questionnaires before exams, incorporating stress-inducing imaginative scenarios unrelated to the exams themselves (akin to Peacock and Wong's Study 2). In a different vein, Nazaré and Fonseca (2021) instructed 245 women to *recollect* the birth of their first child prior to completing the modified SAM. In this case, this methodology might be associated with recall biases and pose questions regarding the extent to which the questionnaire measured *anticipation* of the event.

Consequently, Durak and Senol-Durak's (2013) efforts stand out as the sole validation study to administer the SAM prior to a self-reported stressor of choice (e.g., midterm exam, difficulties with course projects, difficulties with partner in the upcoming four weeks) without prior stress induction. Clear and relevant instructions tailored to the research objectives should be provided across all studies to minimize the potential for variation in participant responses. Additionally, researchers should carefully consider the scenarios presented to participants, ensuring their direct relevance to the constructs being measured.

Furthermore, the phrasing of items in previous versions also prompts inquiries about the response variability across different languages. For example, the first item in the English and French scales, "Is this a totally hopeless situation?", inclines toward eliciting a more dichotomous response. While the scale provides a range of agreement levels (e.g., "not at all" to "extremely"), it creates a potential mismatch between the item's wording and the available response options. The contrast between the extremeness of the wording and the nuanced response options may lead to potential response biases, reduced discrimination, and potential confusion for respondents (e.g., Purgato & Barbui, 2012). In line with these observations, we sought to suggest item rephrasing that may mitigate such influences.

Current Study

Taken together, these studies confirm an instability in the SAM scale across several languages. Although they allow for comparisons with the original English version, a major limitation in the mentioned studies is the consideration of the SAM subscales as being orthogonal, by implementing PCA with varimax rotation. This method fails to account for the correlations reported between most factors across all validation studies. Additionally, variations in questionnaire instructions and item phrasing may have further contributed to the fluctuations in the factor structure, including for the earlier French adaptation.

Therefore, the main goal of the current study was to offer a new French version of the SAM that accounts for these limitations. We sought to replicate the six-factor structure based on Peacock and Wong (1990)'s initial theoretical model, in direct response to an upcoming, ecological stressor that is common across all participants (i.e., university examinations without any additional, unrelated stress induction), while accounting for the inter-factor correlations. Moreover, as only Peacock and Wong (1990) provided estimates of instrument validity, we aimed to supplement the French scale with further construct, convergent, and discriminant validity.

A.2 Study 1: Exploratory Factor Analysis of the SAM

Aim and Hypotheses

This study and its hypotheses were preregistered on the Open Science Framework (OSF) ahead of data collection, on December 17th, 2020 (https://osf.io/765dw). The objective of the first study was to validate Peacock and Wong's (1990) Stress Appraisal Measure (SAM) in the French language. This involved addressing the limitations identified in the literature and providing information regarding discriminant and convergent validity. Although the pre-registration included a CFA, the poor internal consistency observed for the challenge construct within our first sample (see Table 20) – in line with previous studies (e.g., Nazaré & Fonseca, 2021; Roesch & Rowley, 2005) – led to the conclusion that an exploratory factorial analysis (EFA) would be more appropriate. Hence, the aim of Study 1 was reframed to begin the exploration of a more optimal factor structure for the SAM in the French language. Ethical approval was obtained from the Saint-Luc-UCLouvain Biomedical Ethics Committee.

Table 20. Information regarding Kurtosis, Skewness, and Internal Consistency for the SAM Subscales in Study 1

	Mean (*SD*)	Kurtosis	Skewness	Cronbach's Alpha	McDonald's Omega
Original SAM Subscales					
Threat (4 items)	2.58 (0.84)	-.53	.12	.75	.74
Challenge (4 items)	3.44 (0.77)	-.42	-.13	.55	.56
Centrality (4 items)	3.69 (0.88)	-.14	-.61	.78	.79
Controllable by Self (4 items)	3.59 (0.71)	-.27	-.10	.87	.87
Controllable by Others (4 items)	3.17 (0.92)	-.63	-.16	.86	.86
Uncontrollable by Anyone (4 items)	1.99 (0.78)	-.42	.61	.71	.71
Stressfulness (4 items)	3.51 (0.75)	.24	.12	.69	.75
Altered SAM Subscales Following EFA					
Threat/Challenge (4 items)	3.49 (0.80)	-.24	-.30	.67	.65
Uncontrollable by Anyone (3 items)	1.87 (0.82)	.04	.82	.69	.71

Note. Conventional cutoffs include +1 (leptokurtic distribution – heavy-tailed) and -1 (platykurtic distribution – light-tailed) for kurtosis, greater than +1 and -1 indicate a significantly skewed distribution (Groeneveld & Meeden, 1984), and a Cronbach's alpha or McDonald's omega value of 0.70 or higher is considered acceptable in research (Nunnally & Bernstein, 1994). All SAM subscales range on a scale from 1 to 5.

Method

French adaptation of the scale

Three French-English bilingual researchers in psychology in possession of a Ph.D. degree completed the forward-translation to the French language, while three English-French bilingual researchers performed the backward-translation. Translation differences were discussed between the first and the last author. Following questionnaire validation recommendations (Boateng et al., 2018; Hilton, 2017), the questionnaire was administered to a sample of 42 individuals (age, M = 41.74, SD = 22.04, range 18 to 86; 71.40% female; years of education, M = 15.26, SD = 2.88, range 12 to 24) for a preliminary pilot testing. The study was conducted online on Qualtrics (Provo, UT) due to Covid-19 restrictions in place at the time. To begin with, participants completed the SAM. Then, the survey presented each item and the corresponding participant's response. Individuals wrote an explanation for the answer they had provided, rated the item's degree of clarity, and offered recommendations regarding grammar and syntax. The scale instructions in the French version were modified for overall coherence, with all items starting with "Currently, to what extent..." Following the modifications, the questionnaire was further discussed among the team before being administered to a new sample for its validation. The final French version of the SAM is available as supplementary materials on OSF (https://osf.io/fwegn/).

Participants

The sample consisted of Belgian university students, who were recruited either from a first-year psychology class in the Faculty of Motor Sciences (N = 418) or from a mailing list sent out to older students of the Faculty of Psychology and Educational Sciences (aged 30 and above, N = 71). The former participated in exchange of course credit, while the latter were entered into a raffle ticket with a chance to win 25 euros. Participants were excluded from the study if they were not undergraduate students, if they were less than 18 years old, if they did not have an exam in January 2021, and if they were not native French speakers. The target sample size of 300 individuals was determined based on recent recommendations for questionnaire validation studies (Arafat et al., 2016; Boateng et al., 2018; Comrey & Lee, 2013; Tsang et al., 2017).

Individuals with missing data (N = 43) and who failed the attention check item in the first questionnaire (N = 15) were removed from data analysis. A further six individuals were excluded from analysis due to presenting extreme data (more than three S.D. from the mean) on the SAM controllable-by-self subscale (N = 1), on the SAM uncontrollable-by-anyone subscale (N = 1), on the maladaptive coping composite score (N = 3), and on both the SAM uncontrollability subscale and maladaptive coping score (N = 1). The remaining participants included in the analyses (N = 425) were aged 18 to 54 (M = 21.61; SD = 7.27), 53.9% were women, and presented an average of 13.21 years of education (SD = 2.36).

Measures

The SAM (Peacock & Wong, 1990) consists of 28 items evaluated along a Likert scale ranging from 1 (not at all) to 5 (very much). The original instructions of the scale prompt individuals to estimate the extent to which they agree or disagree with each item. For each subscale, the final score was computed as the average of the corresponding four items, with higher scores indicating a greater perception of that specific type of appraisal. Table 20 presents the internal consistencies.

Procedure

Intending initially to assess construct, convergent, and divergent validity, we also gathered data on the constructs described in Study 2. These included questionnaires measuring trait cognitive appraisal (Cognitive Appraisal Scale, Skinner & Brewer, 2002; French validation of the scale: Berjot & Girault-Lidvan, 2009), perceived stress (Perceived Stress Scale, Cohen et al., 1983; French validation: Bellinghausen et al., 2009), depressive symptomatology (Center for Epidemiological Studies-Depression Scale, Lewinsohn et al., 1997; French validation: Fuhrer & Rouillon, 1989), coping (Brief-COPE, Carver, 1997; French validation: Muller & Spitz, 2003), and social desirability (Marlowe-Crowne Social Desirability Scale; Reynolds, 1982; French validation: Verardi et al., 2010). However, as noted above, Study 1 ultimately focused solely on establishing the factor structure of the SAM. Thus, responses to these measures were not used for the present analyses. All questionnaires were administered online and randomized for each participant on Qualtrics (Provo, UT). Participants received the questionnaires a week before the start of their January 2021 examination session and were to complete them at most the day before their first examination.

Data analysis

The preregistration information and supplementary materials associated with the current research are available on OSF. The database and/or script are available upon request. Across all sets of analyses, individuals presenting missing data, having completed the questionnaire after their first examination, representing an outlier on one of the SAM subscales (more than 3 *SD* above the subscale mean), or having failed the attention check item at either Time 1 were removed from analyses. To ensure participants' attentiveness and thorough understanding of the questionnaires, the attention check item was included within the Brief-COPE questionnaire. Specifically, participants were explicitly instructed to respond with "a little" to item 14. In the data analysis, all other responses to this item were considered an exclusion criterion, as we interpreted them as a sign that participants may not have paid sufficient attention to the questionnaire instructions. Given the potential influence of outliers on the number of factors retained in EFAs (Liu et al., 2012; Liu & Zumbo, 2012), we ran analyses on the sample with and without outliers. As the results do not change, the results we report correspond to the sample without outliers.

Regarding the examination of the factorial structure, our aim was to identify the latent constructs underlying factor correlations, rather than striving to reduce a large number of variables to smaller components (Jackson et al., 2009). Therefore, in contrast to previous SAM studies (Peacock & Wong, 1990; French version, Pelchat et al., 1995), we applied a factor analysis. Further, given the abnormal distribution of the data (skewness and kurtosis values are available in Table 20), and that it has been previously shown to be more robust than Principal Axis Factoring (Lloret et al., 2017), we selected the Unweighted Least Squares method for the EFA (Schreiber, 2021) and we reported Spearman correlations between all items. Based on previous studies on the SAM structure, we applied a direct oblimin rotation, as we expected our factors to correlate. Before conducting the EFA, violations of statistical assumptions were tested as recommended (e.g., Howard, 2016; Schreiber, 2021) using the Kaiser-Meyer Olkin Measure of Sampling Adequacy (required to be higher than .60; Kaiser, 1970) and Bartlett's test of sphericity (which should be significant; Williams et al., 2010).

Factor extraction was decided based on Kaiser Eigenvalues, scree plot visualization, parallel analyses, comparison data (Ruscio & Roche, 2012), the Hull method (Lorenzo-Seva et al., 2011), and theoretical considerations (Goretzko et al., 2021; Schreiber, 2021). Higher trust was placed on the latter three, as greater empirical findings support their efficacy (Bandalos & Finney, 2018). In the case of cross-loadings, item retention was based on the fact that they did not simultaneously load onto another factor above 0.30, and if they were to cross-load, they presented at least a difference of 0.20 between the two (Boateng et al., 2018; Howard, 2016). We herein report p-values and consider results as significant when they fulfill the criterion $p<.05$. In light of the criticisms raising against Cronbach's Alpha, it was decided to complement its use with the McDonald's Omega (McDonald, 1999; McNeish, 2018; Savalei et al., 2019). Values above .70 were interpreted as having good reliability. Parallel and comparison data analyses were conducted using the "psych" and "EFATools" packages on RStudio (Version 1.4.17.17), respectively. Finally, to replicate the regression models proposed by Peacock and Wong (1990) and the subsequent translation efforts in other languages, we conducted a stepwise linear regression model to predict stressfulness as measured by the SAM. Each subscale was entered as an individual predictor at each step, starting with the new threat-and-challenge appraisal subscale. IBM SPSS Statistics 25 (2017) was used for all other analyses.

Results

Factorial analysis

The Kaiser-Meyer Olkin index (0.86) was above the minimum standard required (Lloret et al., 2017), while Bartlett's test of sphericity was significant [$\chi2$ (276) = 4103.38, $p<.001$], confirming the correlation matrix was not random. Bivariate Spearman correlations revealed a lack of multicollinearity, with correlations ranging between 0.001 and 0.721 across all items included in the factor analysis (see Supplementary Materials,

Table S1), with no correlation above .80 (Field, 2013). Both tests render the data suitable for further analysis (Schreiber, 2021; Shrestha, 2021). Moreover, there were no items with initial communalities lower than 0.20. Hence, all were retained for the full extraction procedure.

In terms of factor structure, both the Eigenvalue rule (Kaiser, 1960) and the Scree Plot (Figure S1) on SPSS suggested a five-factor structure. The Parallel Analyses (based on orthogonal method, using both fa.parallel (psych) and EFA (EFA.tools) functions yielded five factors (Figure S2). The Comparison Data procedure (CD function from EFA.tools) suggested seven and eight factors with Pearson and Spearman correlation methods applied, respectively. The Hull estimation with Unweighted Least Squares (ULS; Hull function from the EFA.tools package) suggested between 4 and 7 factors. Consequently, we conducted separate EFAs each with these different factor solutions, and compared each in terms of communalities, explained variance, factors retained, and item loadings. The five-factor structure was retained for two primary reasons. Firstly, it yielded a lower number of cross-loadings and therefore preserved the highest number of items from the original scale. Secondly, it exhibited the highest level of consistency on a theoretical basis. In fact, the five-factor solution closely resembled the initial factor structure, thus preventing the emergence of disjointed subscales with limited interpretative clarity. Furthermore, it remained in alignment with theoretical constructs of threat and challenge, as delineated in the Biopsychosocial Model of Challenge and Threat (Blascovich, 2008). Implications of these findings will be discussed in the subsequent section. The other solutions can be found in Supplementary Materials (Tables S2-4).

Irrespective of the rotation used (oblimin or promax), item 10 (becoming a stronger person) failed to present a factor loading of 0.3 on any of the five factors. Consequently, it was removed, and we ran the analyses a second time without it. The Kaiser-Meyer Olkin index (0.86) and Bartlett's test of sphericity [$\chi 2$ (253) = 3976.18, $p < .001$] confirmed the correlation matrix for this new structure was not random. As a result, several items were revealed to be problematic, presenting important cross-loadings (items 1, 5, 8, and 20). The Pattern Matrix for the five-factor solution can be found in Table 21. Altogether, the five factors explained 60.60% of the variance before rotation. The item structure of Factors 1 (controllable-by-self), 2 (centrality), and 3 (controllable-by-others) were identical to the original scale, with each item loading above 0.40 on their respective factors. The uncontrollable-by-anyone factor was composed of three of the original items. Finally, the factor solution suggested the merging of threat and challenge into one common "Threat/Challenge" subscale, in which items 11 and 28 were reversed, where higher scores represent a higher likelihood to perceive the situation as challenging. The structure matrix replicates these findings (see Supplementary Materials, Table S5). The internal consistency for the uncontrollable-by-anyone scale was similar to its previous version following the removal of one item, while the new Threat/Challenge subscale presented moderate internal consistency (see Table 20).

Table 21. EFA Pattern Matrix for the SAM

	Factor					Communalities
	1	2	3	4	5	
Necessary skills for a successful outcome (25)	**.84**		.10			.61
Skills to handle the situation (14)	**.80**					.62
Ability to deal (12)	**.71**					.59
Feel capable of overcoming (22)	**.63**				.19	.59
Important repercussions for me (13)		**.82**				.55
Important consequences for me (6)	-.22	**.75**			.15	.51
Affected by outcome (9)		**.69**				.41
Affected in the long-term (27)	.12	**.55**				.34
Anxious about the situation (5)	-.34	.43		.12		.42
Threatening situation (20)		.42		.19	-.33	.43
People available to help (23)			**.83**			.58
Help available (15)			**.81**			.60
Person or agency that can help (4)			**.73**			.49
Sufficient external resources (17)	.14		**.71**			.51
Beyond anyone's ability (18)				**.84**	.11	.38
Uncontrollable by anyone (3)				**.60**		.37
Impossible to solve by anyone (21)				**.55**		.32
Negative impact (28)		.23		.11	**-.67**	.52
Negative outcome (11)		.17		.11	**-.63**	.51
Positive impact (7)	.12		.17		**.41**	.32
Enthusiastic about the outcome (19)		.10			**.34**	.22
Desire to face the problem (8)	.17	.19			.33	.22
Hopeless situation (1)	-.20	.13		.29	-.31	.46

In our inter-item correlation analyses (see Table S1), we also found moderate Spearman correlations (ranging from .21 to .43) between items in the primary appraisal and controllable-by-self subscales. People who scored higher in challenge appraisals also saw situations as more personally controllable, and vice versa. Smaller but significant correlations (ranging from .20 to .33) were seen between primary appraisals, controllable-by-self, and items from controllable-by-others and uncontrollable-by-oneself.

Finally, the additional stepwise regression model extended previous findings. In contrast to previous studies (Peacock & Wong, 1990; Pelchat et al., 1995) that found only threat, challenge, and centrality to predict stressfulness, all five factors in our study significantly predicted stressfulness of the upcoming examination session, with significant F changes at each step. The complete regression model with all five factors is significant [$F(5,424)=52.73$, $p<.001$], with standardized coefficients ranging from .10 (controllable by others) to .47 (centrality; see Supplementary Materials for the full table, including R^2 change with each added subscale, Tables S6-7). The collinearity statistics did not reveal any problems.

Study 1 Discussion

The aim of this first study was to examine the factorial structure of the original SAM in the French language, and to provide evidence of its construct, convergent, and discriminant validity. However, despite modifications in instructions and item wording, the challenge factor exhibited low internal consistency, mirroring past validation efforts in other languages (e.g., Delahaye et al., 2015, Pelchat et al., 1995). To propose a stress appraisal scale with better internal consistency that also accounts for between-factor correlations, we opted for EFA over CFA.

The EFA replicated the overall factor structure of the original SAM (Peacock & Wong, 1990) in the French language. However, according to the results, significant changes to the initial English version are required, namely the removal of five items and the subsequent bridging of the threat and challenge subscales as a single dimension. In addition, in contrast to previous studies, the EFA brought evidence for the independence of centrality as a subscale.

Item Removal

Uncontrollable by anyone

The current analysis has led to the proposed removal of one item from uncontrollable-by-anyone initial subscale, and two from both challenge and threat. Regarding the former, item 1 (totally hopeless) was problematic: it cross-loaded onto threat-and-challenge, uncontrollable-by-anyone, and controllable-by-oneself. With these results, we replicated a problem that arose in the original English validation by Peacock & Wong (1990): while item 1 loaded weakly onto threat in the second study, it failed to saturate altogether in their third study. Similar cross-loadings results are reported in previous French and German versions. Pelchat and colleagues (1995) argue that the item fails to measure the construct of threat altogether. The wording conveys a general perception of despair (e.g., closer to primary appraisal) rather than the ability to have an impact upon the upcoming event (i.e., uncontrollable-by-anyone). Accounting for these observations, we recommend removing this item from the SAM.

Challenge

With respect to challenge, three main issues were observed, namely poor internal consistency, lack of factor loading for item 10 (becoming a stronger person), and important cross-loadings of item 8 (desire to tackle the stressor). With respect to internal consistency, Pelchat and colleagues' (1995) also found considerably poor internal consistency for the challenge subscale in their first study (α = .40), a finding that was replicated in the current study despite changes in the wording of items. In line with their results, the inter-item correlations for challenge in our study were relatively low, with Spearman correlations ranging from .15 to .36. The lower correlations signal problems with the challenge items in the French validation. However, it is difficult to conclude this being a problem in the French language only, with inter-item correlations not being reported in validation studies in other languages (Delahaye et al., 2015, Peacock & Wong, 1990).

In addition to poor internal consistency, we removed item 10 (becoming a stronger person) prior to factor analysis, as it failed to load entirely onto a factor. While one may interpret this finding as the result of inadequate translation of the item in our French version, it is important to note that the formulation for this item is almost identical to the formulation suggested by Pelchat and colleagues (1995) in their second study, where item 10 loaded at .72 onto challenge. Delahaye and colleagues (2015) also report a factor loading of .76 for this item. In contrast, Peacock and Wong (1990) reported a lower loading of .42 (compared to .64 for eager to tackle and .70 for excited about outcome). However, all three studies show other challenge items cross-loading onto other factors, if not entirely. Hence, the varying structure loadings for challenge depending on the validation study, irrespective of language, confirm issues with this subscale.

In fact, item 8 (desire to tackle the stressor) presented important cross-loadings with controllable-by-self in our study. This cross-loading was also observed by Pelchat and colleagues (1995; .44 for controllable-by-self and .53 for challenge), while item 8 factored completely onto controllable-by-self in the German version (.73), and cross-loaded onto only threat (.36) and controllable-by-self in the Turkish version (.45). The replication of previous reports thereby confirms persistent problems with the challenge items that we wish to address. In light of our findings, we recommend the removal of both items 8 and 10 from the scale.

Threat

With respect to threat, item 5 (makes me anxious) also showed significant cross-loadings with controllable-by-self. Our findings differ from previous French, German, and Turkish language validation studies, where item 5 loaded onto a centrality-threat common factor. In the English original study, this factor loads with .56 onto threat. This difference is possibly due to a difference in wording: our item is a direct translation of the English version "makes me anxious", while Pelchat and colleagues (1995) adapted the item into “this situation worries me”. However, both Delahaye and colleagues (2015) and Durak & Senol-Durak (2013) employed a similar wording as us. While it may be tempting to consider this item as representing centrality, we believe it fails to represent the underlying concept itself.

Although perceptions of threat may lead to anxiety or be associated with worry, we assert that appraisals of threat should remain distinct from negative affect and cognitive processes. Consistent with this perspective, the Spearman correlations between item 5 and the threat-related items (ranging from ρ = .36 to .40) are greater compared to those with centrality-related items (ranging from ρ = -.29 to -.39). More notably, the correlations are highest with the Stressfulness items (ranging from ρ = .26 to .79). Our interpretation rests on the notion that the anxious item predominantly represents overall stress levels rather than an appraisal of threat, aligning with Lazarus and Folkman’s (1984) theoretical model.

Threat and Challenge

Altogether, the bridging of threat and challenge brings interesting theoretical considerations for the concept of primary appraisal. The SAM was initially based on the transactional model of stress appraisals (Lazarus & Folkman, 1984), in which challenge and threat co-occur separately each with their own continuum (e.g., Meijen et al., 2020; Skinner & Brewer, 2002). Models developed in the sports domain have also vouched for a bivalent activation of challenge and threat appraisals (e.g., see Uphill and colleagues, 2019, for a review and the Evaluative Space Approach to Challenge and Threat model). However, it is important to note that cross-loadings between challenge and threat had previously been reported in English [item 7 (positive impact) loaded at -.44 onto threat] and German [item 19 (excited about the outcome) at .73], indicating that the scale items, as they were formulated, seemingly tapped into the same construct.

The newly proposed structure for the SAM aligns more closely with a competing perspective in the literature, wherein threat and challenge are positioned along the same continuum (e.g., Jones et al., 2009). Notably, one of the key features of the Biopsychosocial Model of Challenge and Threat (Blascovich, 2008) asserts that challenge and threat cannot coexist concurrently (Hase, 2019). The continuum spans from an “adaptive” to a “maladaptive” state, representing challenge and threat respectively. The two states can be distinguished from one another based on distinct physiological responses to events, where cardiovascular responses to threat are attributed to hypothalamic-pituitary-adrenal axis activity countering sympathetic-adrenomedullary effects through cortisol release. Reflecting this theoretical framework, Tomaka and colleagues (2018) have developed the Appraisal of Challenge or Threat Scale, which measures the tendency for individuals to appraise events as challenging or threatening.

Although our primary objective did not involve assessing the supporting evidence for these approaches, our results suggest that the scale is more in line with this second model of challenge and threat appraisals. Researchers should keep these theories in mind when utilizing the SAM. Should researchers find themselves inclined towards a more distinct differentiation of challenge and threat, we propose exploring potential adjustments to enhance the challenge subscale, an aspect we will delve into further during the general discussion.

Threat and Centrality

In contrast to previous studies, the use of oblique rotation confirmed the relative independence of centrality from threat and challenge when one accounts for subscale inter-correlations. Item 20 (threatening situation) was the only item to retain important cross-loadings with centrality, despite the use of an oblimin rotation. We thereby recommend users to remove it from the threat/challenge subscale.

It appears that factoring issues for centrality discussed previously arose not so much because of language issues, but perhaps from the lack of consideration of the interdependence of the factors. Using the new proposed structure, threat/challenge, and centrality were not significantly associated with one another. Moreover, additional regression analyses confirmed that all five factors significantly predicted stressfulness. The collinearity diagnostics did not report any problems in tolerance or VIF, further confirming the distinctive nature of these five factors. Hence, we recommend the use of the SAM for researchers that strive to investigate the roles of different types of primary and secondary appraisals. Given the removal of original items leading to this new five-factor structure, a cross-validation in a second, independent sample is required for confirmation of the new subscales and overall scale structure.

A.3 Study 2: The five-factor SAM: Confirmatory Factor Analysis and Scale Validity

Aims and Hypotheses

As a follow-up to the new SAM structure, the first objective of the second study was to run a CFA on a new sample, as such to confirm the five-factor structure and its constructs. Second, we aimed to examine the construct, convergent, and discriminant validity.

We hypothesized that we would replicate the five factors that emerged from Study 1, namely threat and challenge, centrality, controllable by self, controllable by others, and uncontrollable by anyone. Moreover, within the SAM, higher threat (i.e., lower challenge) should correlate with lower scores on the controllable by self and others subscales, and with higher centrality, stress, and the uncontrollable by anyone subscale.

We also expected specific correlations to confirm construct and convergent validity. Threat/challenge should correlate strongly with the two respective concepts from the

Cognitive Appraisal Scale (Berjot & Girault-Lidvan, 2009), thereby confirming construct validity. Higher threat (i.e., lower challenge) scores should correlate with higher stress on the Perceived Stress Scale (Bellinghausen et al., 2009), more maladaptive coping and less adaptive coping on the Brief-COPE scale (Muller & Spitz, 2003), and higher scores of depressive symptomatology (CES-D; Fuhrer & Rouillon, 1989), thereby confirming convergent validity. Finally, as previously reported in other studies (Durak & Senol-Durak, 2013), all subscales should not correlate with social desirability. Ethical approval was obtained from the Saint-Luc-UCLouvain Biomedical Ethics Committee.

Method

Participants

The data for this second study comprises the results of two separate studies that were conducted over the same time period (i.e., January 2022 exams). The first sample (Sample 1, SAM CFA dataset, $N = 276$) was recruited online throughout December 2021, using advertisements and social media posts, specifically for conducting a CFA on the five-facet French version of the SAM ahead of the January 2022 undergraduate exams. However, the number of participant responses in this sample was insufficient for the required statistical power for CFA. To address this, we combined this data with that of another unrelated study conducted concurrently. The second sample (Sample 2, Attention dataset, $N = 110$) was recruited for a study aiming to evaluate the role of attentional networks in stress-related mechanisms before the university exams in January 2022. It included several of the same questionnaires used in the first sample, including the SAM.

The two samples did not overlap, in that they were recruited separately from one another, and participation in both studies was rendered impossible. Participants entered a lottery system with a raffle ticket for a chance to win 25 euros or were compensated with course credits (Sample 2 only). Participants were excluded from both studies if they were not undergraduate students, if they were less than 18 years old, if they did not have an exam in January 2022, and if they were not native French speakers.

Participants with missing data across all variables were removed (Sample 1, $N = 55$; Sample 2, $N = 2$), as were those who failed the attention check item (Sample 1, $N = 3$; Sample 2, $N = 2$). In addition, several participants completed the questionnaires after their first examination and were subsequently removed from analysis (Sample 1, $N = 2$; Sample 2, $N = 1$). Screening of outliers on this sample ($N = 318$) led to the removal of ten additional participants for the final analyses (Centrality, $N = 2$; Uncontrollable by anyone, $N = 5$, Maladaptive coping, $N = 3$). Participants were aged 18 to 48 ($M = 20.39$, $SD = 4.13$), 80.80% were women, and the average years of education was 13.57 ($SD = 1.76$)[1]. The

[1] In the Belgian education system, completing 12 years of schooling corresponds to the attainment of secondary school education. The average of 13 years in this sample suggests that most participants were in their first year of undergraduate studies.

gender distribution in Study 2 differs from that of Study 1, and this disparity can be attributed to differences in recruitment strategies. Participants in Study 1 were reached through a mailing list to the Faculty of Movement and Rehabilitation Sciences and to mature students from the Faculty of Psychology. In contrast, Study 2 recruited participants across all academic years from the Faculty of Psychology only. Consequently, this resulted in a higher representation of female students, leading to the observed discrepancy.

Measures

The administered questionnaires are identical to those presented in Study 1.

Stress Appraisal Scale

Both studies administered the SAM in the French language, online on Qualtrics (Provo, UT). The internal consistency for all five facets was high (see Table 22).

Construct validity: cognitive appraisal

We used the Cognitive Appraisal Scale (Skinner & Brewer, 2002) to evaluate construct validity. Validated in French (Berjot & Girault-Lidvan, 2009), the scale measures individuals' general tendency to evaluate situations as threatening (10 items) and/or challenging (7 items). The questionnaire is composed of 17 items rated from 1 (strongly disagree) to 6 (strongly agree). In the current study, threat and challenge assessments respectively displayed good internal consistency (see Table 22).

Convergent validity

Perceived stress. The Perceived Stress Scale (Cohen et al., 1983; French version: Bellinghausen et al., 2009) was administered to evaluate stress over the last month. The scale was composed of 10 items, four of which needed to be reversed. All items were assessed on a Likert scale ranging from 0 (never) to 4 (very often). The total sum score represented an index of chronic stress. In Study 2, the Perceived Stress Scale presented good internal consistency as seen in Table 22.

Depressive symptomatology. Depressive symptoms were included to measure convergent validity using the French version of the Center for Epidemiological Studies-Depression Scale (CES-D, Lewinsohn et al., 1997; French validation: Fuhrer & Rouillon, 1989). Participants were invited to specify the frequency with which they experienced specific feelings over the previous week, on a scale ranging from 0 [Never/Very rarely (less than a day)] to 3 [Frequently/All the time (5-7 days)]. The degree of severity of depressive symptoms was calculated as the sum of all items, after reversing four scores. The internal consistency of the CES-D was replicated in this study (Table 22).

Table 22. Information regarding Kurtosis, Skewness, and Internal Consistency for the SAM Subscales and Associated Variables in Study 2

	Mean (SD)	Range	Kurtosis	Skewness	Cronbach's Alpha	McDonald's Omega
SAM Subscales						
Threat/Challenge (4 items)	3.25 (0.88)	1.00-5.00	-.29	-.28	.75	.73
Controllable by Self (4 items)	3.46 (0.81)	1.25-5.00	-.48	-.11	.91	.91
Controllable by Others (4 items)	3.03 (1.01)	1.00-4.00	-.92	.02	.89	.90
Uncontrollable by Anyone (3 items)	1.71 (0.74)	1.00-4.00	.24	.99	.70	.71
Centrality (4 items)	4.02 (0.80)	1.75-5.00	-.09	-.70	.80	.80
Stressfulness (4 items)	3.66 (0.76)	1.50-5.00	-.51	-.40	.73	.79
Associated Variables						
Perceived Stress	21.66 (6.80)	4.00-37.00	-.31	-.22	.88	.88
Depressive Symptoms	25.23 (6.80)	2.00-56.00	-.66	.17	.91	.80
Adaptive Coping	35.76 (7.49)	18.00-55.00	-.20	.01	.85	.81
Distraction	2.46 (0.75)	1.00-4.00	-.48	.17	.55	-
Denial	1.33 (0.56)	1.00-4.00	3.67	1.95	.61	-
Substance Use	1.25 (0.60)	1.00-4.00	9.12	2.95	.94	-
Behavioral Disengagement	1.43 (0.57)	1.00-3.50	.66	1.19	.69	-
Self-blame	2.47 (0.86)	1.00-4.00	-.96	.06	.64	-
CAS Threat (*N* = 208)	40.77 (11.00)	17.00-58.00	-.83	-.51	.87	.91
CAS Challenge (*N* = 208)	25.51 (6.14)	11.00-39.00	-.62	-.20	.76	.75
Social Desirability (*N* = 208)	19.07 (2.36)	13.00-25.00	-.35	.00	.53	.53
Anticipatory Examination Stress (*N* = 96)	5.31 (1.44)	1.60-8.80	-.09	-.19	.73	.73

Note. All descriptive analyses were conducted on the full sample (*N* = 308) unless indicated otherwise. McDonald's Omega cannot be calculated on two items. *CAS* = Cognitive Appraisal Scale.

Coping. To measure the convergent validity of threat and challenge with adaptive and maladaptive coping, the French version of the Brief-COPE was used (Carver, 1997; French validation of the scale: Muller & Spitz, 2003). The items were slightly modified so that it was clear for participants to indicate the extent to which they used 28 coping strategies ahead of the upcoming exams, on a 4-point scale from 1 (I haven't been doing this at all) to 4 (I've been doing this a lot). The scale in its original form allows researchers to calculate scores for 14 different coping behaviors (2 items each), namely active coping, planning, instrumental support, emotional support, emotional expression, positive reappraisal, acceptance, denial, self-blame, distraction, substance use, behavioral disengagement, humor, and religion. We averaged scores from the first seven categories (active coping to acceptance) to create a score for adaptive coping. Maladaptive coping was measured by averaging the scores from the denial to behavioral disengagement coping strategies (Meyer, 2001).

While the internal consistency of the Adaptive Coping subscale was good (see Table 22), the McDonald's Omega for maladaptive coping was poor (Ω = .36, α = .63). Consequently, we opted for analyzing correlations between each subscale of the maladaptive coping behaviors. It is important to note that the internal consistency for the distraction, denial, self-blame, and behavioral disengagement subscales are also below the acceptable threshold (α = .55, .61, and .64, .69 respectively). Consequently, we call for caution when interpreting the correlations with these subscales.

Examination stress. To measure stress induced by the upcoming examination session, participants completed five questions referring to the characteristics of stressful situations, including control over the situation (which was reversed), unpredictability of the situation, novelty of the situation, threat over one's ego, and abilities, and subjective perceived stress. All questions were answered on a visual analog scale ranging from 0 (total absence) to 10 (highest level), based on work by Lesage and colleagues (2012) and the Center for Studies on Human Stress (2019). The average was used as the dependent variable, with higher scores indicating greater anticipated stress.

Discriminant validity: social desirability

To evaluate discriminant validity, the French version of the Marlowe-Crowne Social Desirability Scale (Reynolds, 1982; French validated version: Verardi et al., 2010) was selected, as it is conceptually distinct from stress and stress appraisals. This decision was guided by previous successful validation efforts of the Stress Appraisal Measure (SAM) by Roesch & Roesch (2005) and Durak & Senol-Durak (2013), where they reported minimal or negligible correlations with social desirability. Similarly, several other studies have shown very low (e.g., General Appraisal Measure; Hemenover & Dienstbier, 1996) or non-existent (e.g., Appraisal of Life Events; Ferguson et al., 1999) correlations between social desirability and other stress appraisal measures. Additionally, we aimed to explore the extent to which the SAM might be influenced by socially desirable responding, ensuring improved overall self-report accuracy and the collection of valid data. In the current study, individuals indicated whether 13 statements pertaining to social desirability were true or false. Scores range from 1 to 26, with higher scores indicating higher need for social desirability. In the current study, the internal consistency was relatively low for this scale (Table 22) and removing individual items did not improve the scale internal consistency.

Procedure

For the first sample, the procedure was identical to our Study 1: all participants completed the same version of the SAM questionnaire online on Qualtrics (Provo, UT), one week ahead of their upcoming undergraduate exams in January 2022. They were given until the day prior to their exam to submit their responses. Participants in Sample 2 followed the same timeline as the first sample and completed the same questionnaires, except for the Cognitive Appraisal Scale and Marlowe-Crowne Social Desirability Scale (please see the OSF preregistrations for a full description, Sample 1: https://osf.io/765dw; Sample 2: https://osf.io/th4j7).

Data analysis

The datasets from the two studies were merged. Like Study 1, participants with missing data, who had failed the attention check item, or who had completed the questionnaires after their first January examination were excluded from analyses. In both studies, the attention check item was placed among the Brief-COPE questionnaire and required participants to select the response "a little". All variables were screened for normality and outliers (3 standard deviations from the mean) and removed accordingly.

The CFA was run using the lavaan package (0.6-12) on RStudio (2022.07.1 Build 554). The model was composed of the five subscales identified in Study 1. Given the non-normal distribution of the data, we ran a CFA using ULS. However, given that the model fit indices were also confirmed when applying the maximum likelihood (ML) approach, we report the latter. In terms of recommended fit indices (Bandalos & Finney, 2018), we report the standardized root mean square residual (SRMR) as a measure of absolute fit (with well-fitting model obtaining values less than .05 but an acceptable fit is already observed at SRMR < .08, Hu & Bentler, 1999). The root mean square error of approximation (RMSEA) will be reported for a parsimony-adjusted index, with model fit quantified as close (< .05), reasonably good (.05 < RMSEA < .08), mediocre (.08 < RMSEA < .10), or unacceptable (RMSEA > .10; Browne & Cudeck, 1992). Both the comparative fit index (CFI) and non-normed fit index (Tucker-Lewis Index, TLI) will be used for incremental fit indices, where values close to 1.0 indicate a good fit, with (.99 = "excellent", .95 = "close", .92 = "fair" and .90 = "poor"; Marcoulides & Yuan, 2017). We also report the chi-square value. Additionally, we compared the new model fit to a unidimensional fit using an ANOVA.

To evaluate construct, convergent, and discriminant validity, we conducted Spearman correlations using all participants where that is feasible, given that most variables were non-normally distributed despite the removal of outliers. Where Pearson and Spearman correlation strengths and significances were equivalent, we reported the former. Correlations for the Cognitive Appraisal Scale and Marlowe-Crowne Social Desirability Scale were obtained for Sample 1 only ($N = 208$), as the second study did not administer these.

Results

Factorial analysis

The analysis of the different indices led to the conclusion of a well-fitting five-factor model, with an absence of convergence failures, out-of-bounds parameter estimates, and non-positive definite matrices. The SRMR, representing the discrepancy between the observed sample matrix and that implied by the CFA model is of 0.07, thereby pointing towards a good model fit (SRMR < 0.08). Second, regarding the parsimony of the indices of the model, the RMSEA attests to an acceptable, absolute fit (RMSEA = 0.07, p<.001; Browne & Cudeck, 1992). Finally, with respect to the incremental indices, both the CFI and the TLI provide evidence of a fair model fit (CFI = 0.93; TLI = 0.91; Hu & Bentler, 1999, cited by Sun, 2005). The standardized estimates, covariances, and variances are illustrated in Figure 25.

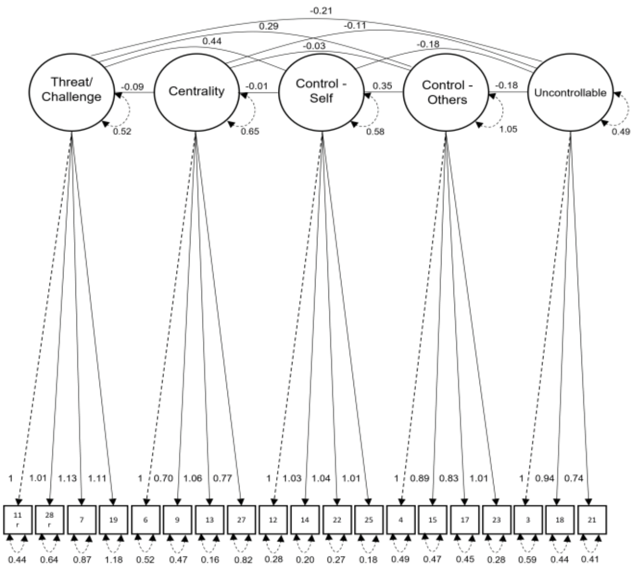


Figure 25. CFA Standardized Estimates, Covariances, and Variances with ML Estimator

The standard error, Wald statistic, and the p-values for the five factors are reported in Supplementary Materials (Table S8). In addition, while the chi-square test is significant [$\chi 2$ (142, $N = 308$) = 348.63, $p < .001$], the relative $\chi 2$ ratio was lower than five (relative $\chi 2$

ratio = 2.46), deeming the model to have a good fit (Schumacker & Lomax, 2004). The unidimensional structure [AIC = 15474, BIC = 15615, $\chi 2$ (152) = 1523.16] showed a significant worse fit compared to the 5-factor model [AIC = 14319, BIC = 14498, $\chi 2$ (142) = 348.63, $\triangle \chi 2$ (10, N = 308) = 1174.5, p <.001), when calculating the models using ML.

Examining scale validity

Convergent validity. Threat/Challenge showed a weak, negative correlation with threat on the Cognitive Appraisal Scale, while showing a positive, moderate correlation with the corresponding challenge subscale (see Table 23). Centrality did not show any significant correlation with either construct. Most SAM subscales demonstrated weak-to-moderate correlations with perceived stress in the last month, depressive symptomatology, and coping, always in the expected direction. As presented in Table 23, higher perceptions of threat (i.e., a lower score on the new Threat/Challenge subscale) were associated with more perceived stress, more depressive symptoms, and an overall higher choice of maladaptive coping ahead of the upcoming exams (namely more denial, more behavioural disengagement, and more self-blame), all the while being positively correlated with general adaptive coping strategies. Concerning anticipatory stress relating to the upcoming examination session, centrality was the only SAM subscale that failed to show a significant association.

In terms of secondary appraisals, both controllable by self and controllable by others presented similar patterns of correlations to the threat-and-challenge subscale. Stronger associations were observed for coping and controllable by oneself compared to that by others. The correlations were weaker for uncontrollable by others compared to oneself. In contrast, higher perceptions of the situations being uncontrollable by anyone displayed the opposite pattern of correlations to controllable subscales. The perception of the event as uncontrollable correlated moderately and positively with higher examination and chronic stress, depressive symptoms, and maladaptive coping.

The SAM stressfulness subscale showed the strongest, positive, and significant correlations with chronic stress and depressive symptoms. It was also associated with higher maladaptive coping scores but was unrelated to adaptive coping. Interestingly, in the second sample, it also correlated moderately with anticipatory stress relating to the upcoming examination session.

Discriminant Validity. As expected, social desirability was not significantly correlated with the SAM factors.

Study 2 Discussion

The objective of the second study was to confirm the new five-factor structure and to evaluate the associations of the SAM subscales with related constructs. The analyses confirmed a good model fit for the five-factor model in the French language, which was also significantly better than a one-factor model. The correlations further supported the separate contributions of the subscales and their expected associations with similar stress-related concepts.

All correlations are in line with the abundant literature regarding the framework of appraisals, coping, and stress (e.g., Skinner & Brewer, 2002). One interesting finding is that while SAM challenge displayed a positive, moderate, and significant correlation with challenge as measured through the Cognitive Appraisal Scale, the association with threat was significant but weaker. Nonetheless, these weaker correlations were expected, as the Cognitive Appraisal Scale measures trait – rather than state – appraisals. In addition, over half of the items for threat on the Cognitive Appraisal Scale measure worry about the impression or image that one might be giving to other people, while the other items measure stress and self-confidence. This differs significantly from the threat items proposed in the SAM. Despite these observations, the directionality of the correlations is in line with the predicted hypotheses, thereby suggesting common underlying concepts being tapped by both the Cognitive Appraisal Scale and the SAM. Interestingly, this held to be true despite the removal of items from the threat and challenge subscales, along with their bridging together under a unique subscale.

Similarly, higher perceptions of controllable-by-oneself presented stronger correlations with challenge on the Cognitive Appraisal Scale compared to the threat/challenge subscale itself. Looking at the Cognitive Appraisal Scale challenge items, one can see that the wording of most relates to the efforts that an individual may implement, and how these lead to positive outcomes. Hence, rather than focusing solely on the perception of stressful situations as challenging, these items also relate, to a certain degree, to the efforts and controllable actions one may implement for the situation to be perceived as such. Given the directionality and significance of the correlations observed in this second study, we retain this new five-factor SAM structure as a solution to the previous caveats reported with the original scale and with later validation efforts in other languages.

A.4 General Discussion

Given the importance of the Stress Appraisal Measure in the stress research, our initial objective was to confirm the previously reported six-factor structure and to provide construct, convergent, and discriminant validity of the scale in the French language. However, the poor reliability coefficient of the challenge subscale obtained in our first study replicated the varying factor structure found in previous translation efforts. Thus, the objective of the first study was to conduct an EFA in the hope of proposing a new scale arrangement given the data. The latter revealed a five-factor structure, in which threat and challenge combined into a unique subscale. Then, as a second step, we conducted a follow-up study to confirm this new model using CFA on a new sample, and to provide the aforementioned validity for the scale in the French language. Our results bring significant changes to the English version, namely with the removal of five items and the creation of a threat/challenge subscale as opposed to one. In contrast to past studies, centrality emerges as an independent subscale. Additionally, the subscales remain separate from social desirability, ensuring the absence of response bias among participants.

Primary appraisals

Both Studies 1 and 2 suggest the bridging of threat and challenge onto one continuum of primary appraisal, where higher scores on this scale represent higher challenge appraisals. Although the initial intention of the SAM was to propose a more granular approach to primary appraisals (Peacock & Wong, 1990), this new structure remains consistent with other theories such as the Biopsychosocial Model of Challenge and Threat (Blascovich, 2008). The new SAM structure also provides appraisal researchers with a questionnaire that can move beyond primary appraisals (e.g., in contrast to Tomaka and colleagues, 2018), situations relating to performance in sports (Rossato et al., 2018), or health conditions (Kessler, 1998).

As a reminder, two items from challenge were removed: desire to become a "stronger person" and "eager to tackle the stressor." Looking at other appraisal models, challenge is usually reflected in situations having the potential for gain, growth, mastery, or rewards (e.g., Blascovich, 2013; Podsakoff et al., 2007). In this sense, "becoming a better person" in the SAM may have been too abstract for participants. Perhaps, for some students, completing an examination may not represent a pillar value to becoming a stronger person. With respect to the second item, it is possible that University examinations may not generally be perceived as events that people are eager to tackle. In fact, they are often seen as stressful and anxiety-provoking events. This is because university examinations are a major determinant of a student's academic success, and they can have a significant impact on their future career prospects. Future studies with the SAM in the context of university examinations should also take into consideration perceived exam difficulty and stakes, as well as student personality and preparation.

It is interesting to question whether these two items are also appropriate for measuring challenge, per se. According to a review on the subject (Carpenter, 2016), the scale most aligned with Lazarus and Folkman's (1984) framework remains the Cognitive Appraisal of Health Scale (CAHS; Kessler, 1998). The authors highlight the need for challenge to represent an opportunity for mastery or gain, even when dealing with tough situations and challenges to one's well-being. In the CAHS, the challenge subscale is composed of five items that tap into these aspects, focusing on whether the individual can overcome (item 30), beat (item 11), or control (item 13) the situation, as well as whether the individual can learn about oneself (item 26) or whether the situation won't get [them] down (item 14). The Cronbach alpha was good ($\alpha = .85$ in the pilot study and $\alpha = .72$ in the main study). In comparison, the current challenge and threat subscale is highly focused on a polarized (positive vs. negative) appraisals of the situation which may limit construct validity. We discuss scale recommendations below.

Limitations

The current studies propose a revised measure of the SAM in the French language for research on stress appraisals. Before suggesting potential improvements for the scale, it is important to discuss potential limitations of our studies. First, in line with previous validation efforts of the SAM, our samples comprised students who were confronted with upcoming university examinations. However, it is important to acknowledge distinctions in both study design and sample characteristics for Studies 1 and 2. Study 1 was conducted in January 2021 during the Covid-19 pandemic; restriction measures were still in place, and the vaccination rollout had not commenced. Hence, it is possible that the appraisal of the examinations was different compared to previous and/or subsequent years.

Moreover, as previously mentioned, there are noticeable variations in gender distribution between the samples of Studies 1 and 2 due to distinct recruitment strategies. Nonetheless, despite these divergences, the factor structure is confirmed in Study 2. This suggests the robustness and appropriateness of the current factor structure, demonstrating its resilience across participant profiles and in the presence of singular stressors.

Future directions for the SAM

Hence, future research should focus on extending the validity of this new structure outside the student population and academic examination stress. Durak and Senol-Durak (2013) have shown preliminary evidence of this with respect to a variety of stressors, thus we recommend that other research teams (English-speaking or otherwise) continue generalizing the scale and its structure for other important life stressors. To stay aligned with Blascovich's (2008) Biopsychosocial Model of Challenge and Threat, the SAM could be used in laboratory settings to evaluate the expected differences in cardiovascular reactivity based on the activated appraisal(s).

Moreover, given that the SAM measures a temporary and transient state, interesting research avenues include investigating time-sensitive changes in primary and secondary appraisals in approach of an upcoming stressful event. This could include administering the SAM multiple times ahead of the stressor and evaluating the reliability of the scale at each time point. Ultimately, this would provide information on changes in appraisals and insights on dynamic interactions with coping processes.

For researchers wishing to capture the potential for co-activation of challenge and threat appraisals, we recommend the addition of new challenge and threat items. Considering the drawbacks linked to single-item scales (e.g., lower precision) – that are used nonetheless – we believe it advisable for research teams to continue applying multi-item assessments for primary appraisal. Challenge should tap more accurately into the idea of a potential for growth despite the required efforts (e.g., see CAHS items). In a similar vein, it is also important that items chosen for threat remain separate from items measuring negative affect.

Nevertheless, the five-factor French version of SAM represents a valid instrument for capturing different types of primary and secondary appraisals in line with the transactional model of stress. Given not only the significant correlations with subjective stress, coping, and depressive symptomatology, but also the validity of the revised structure observed in our two studies, the SAM can be effectively implemented in research projects examining the role of specific cognitive appraisals in anticipation of acute upcoming stressors.

Table 23. Correlations between each SAM Subscale and corresponding Variables for Construct, Convergent, and Discriminant Validity

	Primary Appraisal		Secondary Appraisal			Stressfulness
	Threat and Challenge	Centrality	Controllable by Self	Controllable by Others	Uncontrollable by Anyone	
Age	.03	.07	.05	-.02	-.04	-.11
Gender	.03	.10	-.01	.10	.07	**.21***
Years of Education	.04	.08	.07	.02	-.04	**-.14***
Examination Stress	**-.49*****	.16	**-.53*****	**-.28****	**.47*****	**.58*****
Perceived Stress	**-.51*****	**.20****	**-.58*****	**-.32*****	**.33*****	**.60*****
Depressive Symptoms	**-.50*****	**.23*****	**-.56*****	**-.36*****	**.28*****	**.56*****
Adaptive Coping	**.39*****	**.15****	**.44*****	**.41*****	-.02	-.06
Distraction	.04	.03	.05	.03	-.04	-.08
Denial	**-.15****	.03	**-.26*****	**-.15****	**.14***	**.19****
Substance Use	-.11	-.01	**-.12***	-.10	.10	.11
Behavioral Disengagement	**-.50*****	**.08****	**-.59*****	**-.28*****	**.32*****	**.34*****
Self-blame	**-.40*****	**.18****	**-.45*****	**-.18****	**.13***	**.32*****
CAS Threat	**-.29*****	**.20****	**-.35*****	**-.18****	.10	**.40*****
CAS Challenge	**.56*****	.001	**.65*****	**.29*****	-.07	**-.31*****
Social Desirability	-.02	-.09	.06	.11	.01	-.13

Notes: The Pearson and Spearman correlation strengths and significance are identical for examination stress, chronic stress, depressive symptoms, adaptive coping, maladaptive coping (including distraction, denial, behavioral disengagement, and self-blame), CAS threat, and CAS challenge. Hence, we report the former for these variables. Gender was coded 1 (male), 2 (female) and 3 (other); given the reduced number of participants who identify as "other", sensitivity analyses with binary coding options were conducted and the results did not change (see Supplementary Materials). Values in bold represent significant correlations. $*p < .05$, $**p < .01$, $***p < .001$. CAS = Cognitive Appraisal Scale. When adaptive coping is examined in terms of its subscales, all correlations remain consistent. Significant associations emerge between certain subscales and uncontrollable-by-anyone. Unlike the more general adaptive subscale, which doesn't show such associations, higher perceptions of uncontrollability by anyone are significantly linked to an increased search for emotional support [$\rho(306)=.13$, $p=.026$] and emotion expression [$\rho(306)=.12$, $p=.035$], as well as lower reappraisal [$\rho(306)=-.17$, $p=.003$] and acceptance [$\rho(306)=-.14$, $p=.014$]. Readers are reminded to be cautious while interpreting the maladaptive coping subscales, as some do not show good internal consistency (α = .55-.94; see Table 20).

A.5 Supplementary Materials

All Supplementary Materials can be found at: https://journals.sagepub.com/doi/abs/10.1177/10731911231223120.

Stress Appraisal Measure (SAM) – Translation in French

Actuellement, à quel point...

1 = Pas du tout / 2 = Un peu / 3 = Moyennement / 4 = Beaucoup / 5 = Enormément

1. Cette situation est-elle désespérée ?
2. Cette situation provoque-t-elle une sensation de tension en moi ?
3. Cette situation est-elle hors de contrôle pour n'importe qui ?
4. Y a-t-il une personne ou un organisme vers lesquels je peux me tourner pour obtenir de l'aide en cas de besoin ?
5. Cette situation me rend-elle anxieux(se) ?
6. Cette situation a-t-elle des conséquences importantes pour moi ?
7. Cette situation aura-t-elle un impact positif sur moi ?
8. Ai-je envie de faire face à ce problème ?
9. Serai-je affecté(e) par l'issue de cette situation ?
10. Puis-je devenir quelqu'un de plus fort suite à ce problème ?
11. L'issue de cette situation sera-t-elle négative ?
12. Ai-je la capacité de faire face à cette situation ?
13. Cette situation a-t-elle des répercussions importantes pour moi ?
14. Ai-je les compétences nécessaires pour mener à bien cette situation ?
15. Ai-je de l'aide à ma disposition pour gérer ce problème ?
16. Cette situation mobilise-elle, voire dépasse-t-elle, toutes mes ressources pour y faire face ?
17. Existe-t-il suffisamment de ressources externes qui peuvent m'aider à faire face à cette situation ?
18. La gestion de cette situation est-elle au-delà des capacités de n'importe qui ?
19. Suis-je enthousiaste en pensant au dénouement de cette situation ?
20. Cette situation représente-t-elle une menace pour moi ?
21. Le problème est-il impossible à résoudre par qui que ce soit ?
22. Est-ce que je me sens capable de surmonter le problème ?
23. Existe-t-il des personnes qui pourraient m'aider à gérer ce problème ?
24. Est-ce que je perçois cette situation comme stressante ?
25. Ai-je les compétences nécessaires pour parvenir à une issue favorable ?
26. Cet événement nécessite-t-il des efforts de ma part pour y faire face ?
27. Cette situation a-t-elle des conséquences à long terme pour moi ?
28. Cette situation va-elle avoir un impact négatif sur moi ?

Study 1 - Exploratory Factor Analysis of the SAM

Figures

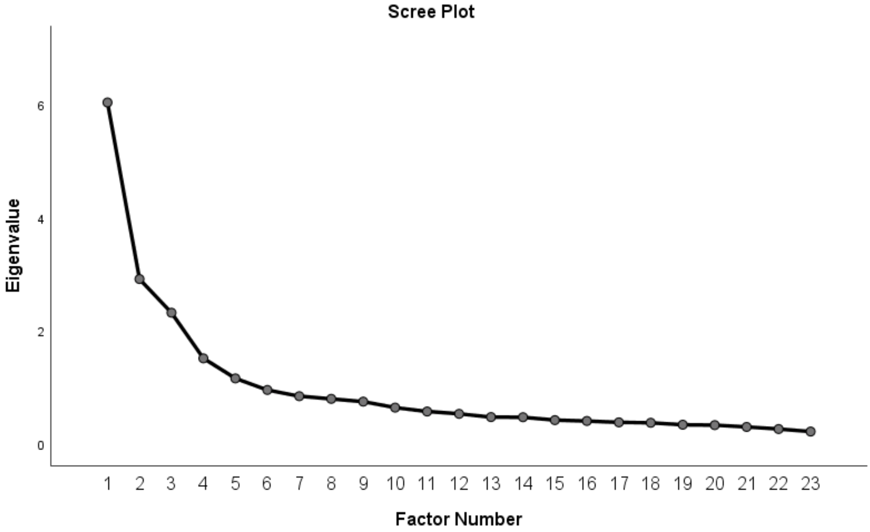


Figure S1. Scree Plot based on the ULS EFA with Oblimin Rotation

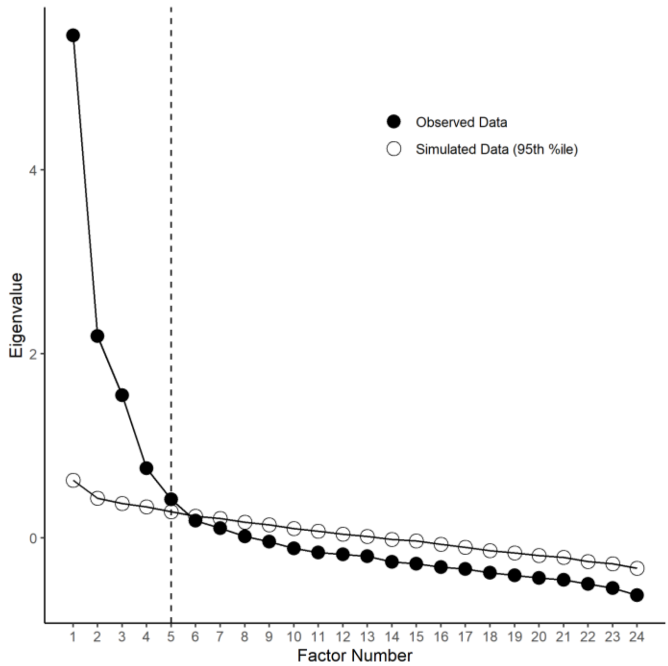


Figure S2. Parallel Analyses Scree Plots

Appendix B:
Supplementary Materials from Chapter 2

B.1 PRISMA 2009 Checklist and PRISMA for Abstracts Checklist

TITLE	CHECKLIST ITEM	PAGE
1. Title:	Identify the report as a systematic review, meta-analysis, or both.	p. 2
BACKGROUND		
2. Objectives:	The research question including components such as participants, interventions, comparators, and outcomes.	p. 2
METHODS		
3. Eligibility criteria:	Study and report characteristics used as criteria for inclusion.	
4. Information sources:	Key databases searched and search dates.	p. 2
5. Risk of bias:	Methods of assessing risk of bias.	
RESULTS		
6. Included studies:	Number and type of included studies and participants and relevant characteristics of studies.	
7. Synthesis of results:	Results for main outcomes (benefits and harms), preferably indicating the number of studies and participants for each. If meta-analysis was done, include summary measures and confidence intervals.	p. 2
8. Description of the effect:	Direction of the effect (i.e. which group is favoured) and size of the effect in terms meaningful to clinicians and patients.	
DISCUSSION		
9. Strengths and Limitations of evidence:	Brief summary of strengths and limitations of evidence (e.g. inconsistency, imprecision, indirectness, or risk of bias, other supporting or conflicting evidence)	p. 2
10. Interpretation:	General interpretation of the results and important implications	
OTHER		
11. Funding:	Primary source of funding for the review.	N/A.
12. Registration:	Registration number and registry name.	

SECTION/TOPIC	#	CHECKLIST ITEM	PAGE
TITLE			
Title	1	Identify the report as a systematic review, meta-analysis, or both.	p. 1
ABSTRACT			
Structured summary	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	p. 2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known.	pp. 3-8
Objectives	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	p. 8
METHODS			
Protocol and registration	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	pp. 8-9
Eligibility criteria	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	pp. 9-10
Information sources	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	p. 10
Search	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	p. 10

Study selection	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	pp. 10-11
Data collection process	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	pp. 11-12
Data items	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	pp. 11-12
Risk of bias in individual studies	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	pp. 12-13
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	pp. 14-15
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I2) for each meta-analysis.	pp. 15-16
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	pp. 26-27
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	pp. 25-26
DISCUSSION			
Summary of evidence	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	pp. 31-36
Limitations	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	pp. 36-37

Conclusions	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	p. 38
FUNDING			
Funding	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	N/A

B.2 Search Strategy

Search Terms

Executive functioning was captured through the keywords “executive function*”, “executive control”, “cognitive function*”, “cognitive control”, “cognitive flexibility”, “fluency”, “attention* control”, “selective attention”, “inhibit* control”, “inhibition”, “planning”, “shifting”, “switching”, “updating”, and “working memory”.

The stress terms comprised “stress exposure”, “stress anticipat*”, “anticipatory stress”, “stress react*”, “stress recovery”, “stress habituat*”, “stress adaptat*”, “repeated stress”, “stress regulation”, “acute stress”, “physiological stress”, “psychological stress”, “self-reported stress”, “subjective stress”, “self-rated stress”, “perceived stress”, “cortisol”, “c-reactive protein”, “interleukin-6”, “heart rate”, “cardiovascular”, “blood pressure”, “norepinephrine”, “epinephrine”, “alpha-amylase”, “skin conductance”, “glucorticoid*”, and “frequency spectral power”.

Finally, we entered the terms “intervention”, “modification”, “program”, and “training” when seeking cognitive interventions.

Search Strings

Cochrane

1. ("Executive control" OR "Cognitive function" OR "behavioral inhibition" OR "cognitive inhibition" OR "behavioural inhibition" OR stroop OR "go/no-go" OR "stop-signal" OR switching OR shifting OR flexibility OR planning OR updating OR fluency OR "inhibitory control" OR "executive function" OR "cognitive control" or "working memory" or "attentional control" OR "selective attention")

2. ("Stress exposure" OR "stress anticipation" OR "anticipatory stress" OR "stress reactivity" OR "stress recovery" OR "stress habituation" OR "stress adaptation" OR "repeated stress" OR "stress adaptation" OR "stress regulation" OR "subjective stress" OR "perceived stress" OR "psychological stress" OR "physiological stress" OR "cortisol" OR "self-reported stress" OR "self-rated stress" OR "subjective stress" OR "c-reactive protein" OR"interleukin-6" OR noradrenaline OR norepinephrine OR "epinephrine" OR "blood pressure" OR "alpha-amylase" OR "cardiovascular" OR "skin conductance" OR "frequency spectral power" OR "heart rate" OR "acute stress" OR glucorticoid)

3. #1 AND #2

4. (("Executive control" OR "Cognitive function*" OR "behavioral inhibition" OR "cognitive inhibition" OR "behavioural inhibition" OR stroop OR "go/no-go" OR "stop-signal" OR switching OR shifting OR flexibility OR planning OR updating OR fluency

OR "inhibitory control" OR "executive function*" OR "cognitive control" OR "working memory" OR "attention* control" OR "selective attention") NEAR (intervention OR modification OR program OR training))

5. #4 AND #2

OpenGray

1. ("executive function*" OR "executive control" OR "cognitive function*" OR "cognitive control" OR "attention* control" OR "inhibit* control" OR "behavior* inhibition" OR "behaviour* inhibition" OR "stroop" OR "stop-signal" OR "go/no-go" OR "cognitive inhibition" OR "cognitive flexibility" OR "planning" OR "shifting" OR "switching" OR "updating" OR "working memory" OR "fluency" OR "selective attention") AND ("stress exposure" OR "stress anticipati*" OR "anticipatory stress" OR "stress react*" OR "stress recovery" OR "stress habituat*" OR "stress adaptat*" OR "repeated stress" OR "stress regulation" OR "acute stress" OR "physiological stress" OR "psychological stress" OR "self-reported stress" OR "subjective stress" OR "self-rated stress" OR "perceived stress" OR cortisol OR "c-reactive protein" OR "interleukin-6" OR "heart rate" OR "cardiovascular" OR "blood pressure" OR "norepinephrine" OR "epinephrine" OR "alpha-amylase" OR "skin conductance" OR glucorticoid* OR "frequency spectral power") English only

2. ((("executive function*" OR "executive control" OR "cognitive function*" OR "cognitive control"OR "attention* control" OR "inhibit* control" OR "behavior* inhibition" OR "behaviour* inhibition" OR "stroop" OR "stop-signal" OR "go/no-go"OR "cognitive inhibition" OR "cognitive flexibility" OR "planning" OR "shifting" OR "switching" OR "updating" OR "working memory" OR "fluency" OR "selective attention") NEAR (modification OR training OR program OR intervention))) AND ("stress exposure" OR "stress anticipati*" OR "anticipatory stress" OR "stress react*" OR "stress recovery" OR "stress habituat*" OR "stress adaptat*" OR "repeated stress" OR "stress regulation" OR "acute stress" OR "physiological stress" OR "psychological stress" OR "self-reported stress" OR "subjective stress" OR "self-rated stress" OR "perceived stress" OR cortisol OR "c-reactive protein" OR "interleukin-6" OR "heart rate" OR "cardiovascular" OR "blood pressure" OR "norepinephrine" OR "epinephrine" OR "alpha-amylase" OR "skin conductance" OR glucorticoid* OR "frequency spectral power") English only

Proquest Dissertations and Theses Global

1. noft(("executive function*" OR "executive control" OR "cognitive function*" OR "cognitive control" OR "attention* control" OR "inhibit* control" OR "behavior* inhibition" OR "behaviour* inhibition" OR "stroop" OR "stop-signal" OR "go/no-go" OR "cognitive inhibition" OR "cognitive flexibility" OR "planning" OR "shifting" OR "switching" OR "updating" OR "working memory" OR "fluency" OR "selective

attention")) AND noft(("stress exposure" OR "stress anticipati*" OR "anticipatory stress" OR "stress react*" OR "stress recovery" OR "stress habituat*" OR "stress adaptat*" OR "repeated stress" OR "stress regulation" OR "acute stress" OR "physiological stress" OR "psychological stress" OR "self-reported stress" OR "subjective stress" OR "self-rated stress" OR "perceived stress" OR cortisol OR "c-reactive protein" OR "interleukin-6" OR "heart rate" OR "cardiovascular" OR "blood pressure" OR "norepinephrine" OR "epinephrine" OR "alpha-amylase" OR "skin conductance" OR glucorticoid* OR "frequency spectral power")) English only

2. noft(("executive function*" OR "executive control" OR "cognitive function*" OR "cognitive control"OR "attention* control" OR "inhibit* control" OR "behavior* inhibition" OR "behaviour* inhibition" OR "stroop" OR "stop-signal" OR "go/no-go"OR "cognitive inhibition" OR "cognitive flexibility" OR "planning" OR "shifting" OR "switching" OR "updating" OR "working memory" OR "fluency" OR "selective attention") NEAR (modification OR training OR program OR intervention)) AND noft(("stress exposure" OR "stress anticipati*" OR "anticipatory stress" OR "stress react*" OR "stress recovery" OR "stress habituat*" OR "stress adaptat*" OR "repeated stress" OR "stress regulation" OR "acute stress" OR "physiological stress" OR "psychological stress" OR "self-reported stress" OR "self-rated stress" OR "subjective stress" OR “perceived stress” OR cortisol OR "c-reactive protein" OR "interleukin-6" OR "heart rate" OR "cardiovascular" OR "blood pressure" OR "norepinephrine" OR "epinephrine" OR "alpha-amylase" OR "skin conductance" OR glucorticoid* OR "frequency spectral power")) English only

PsycInfo

1. noft(("executive function*" OR "executive control" OR "cognitive function*" OR "cognitive control" OR "attention* control" OR "inhibit* control" OR "behavior* inhibition" OR "behaviour* inhibition" OR "stroop" OR "stop-signal" OR "go/no-go" OR "cognitive inhibition" OR "cognitive flexibility" OR "planning" OR "shifting" OR "switching" OR "updating" OR "working memory" OR "fluency" OR "selective attention")) AND noft(("stress exposure" OR "stress anticipati*" OR "anticipatory stress" OR "stress react*" OR "stress recovery" OR "stress habituat*" OR "stress adaptat*" OR "repeated stress" OR "stress regulation" OR "acute stress" OR "physiological stress" OR "psychological stress" OR "self-reported stress" OR "self-rated stress" OR "subjective stress" OR “perceived stress” OR cortisol OR "c-reactive protein" OR "interleukin-6" OR "heart rate" OR "cardiovascular" OR "blood pressure" OR "norepinephrine" OR "epinephrine" OR "alpha-amylase" OR "skin conductance" OR glucorticoid* OR "frequency spectral power")) English

2. noft(("executive function*" OR "executive control" OR "cognitive function*" OR "cognitive control"OR "attention* control" OR "inhibit* control" OR "behavior* inhibition" OR "behaviour* inhibition" OR "stroop" OR "stop-signal" OR "go/no-go"OR "cognitive inhibition" OR "cognitive flexibility" OR "planning" OR "shifting" OR

"switching" OR "updating" OR "working memory" OR "fluency" OR "selective attention") NEAR (modification OR training OR program OR intervention)) AND noft(("stress exposure" OR "stress anticipati*" OR "anticipatory stress" OR "stress react*" OR "stress recovery" OR "stress habituat*" OR "stress adaptat*" OR "repeated stress" OR "stress regulation" OR "acute stress" OR "physiological stress" OR "psychological stress" OR "self-reported stress" OR "self-rated stress" OR "subjective stress" OR "perceived stress" OR cortisol OR "c-reactive protein" OR "interleukin-6" OR "heart rate" OR "cardiovascular" OR "blood pressure" OR "norepinephrine" OR "epinephrine" OR "alpha-amylase" OR "skin conductance" OR glucorticoid* OR "frequency spectral power")) English

Pubmed

1. ((((("executive function*"[Title/Abstract] OR "executive control"[Title/Abstract] OR "cognitive function*"[Title/Abstract] OR "cognitive control"[Title/Abstract] OR "attention* control"[Title/Abstract] OR "inhibit* control"[Title/Abstract] OR "behavior* inhibition"[Title/Abstract] OR "behaviour* inhibition"[Title/Abstract] OR "stroop"[Title/Abstract] OR "stop-signal"[Title/Abstract] OR "go/no-go"[Title/Abstract] OR "cognitive inhibition"[Title/Abstract] OR "cognitive flexibility"[Title/Abstract] OR "planning"[Title/Abstract] OR "shifting"[Title/Abstract] OR "switching"[Title/Abstract] OR "updating"[Title/Abstract] OR "working memory"[Title/Abstract] OR "fluency"[Title/Abstract] OR "selective attention"[Title/Abstract])))) AND Humans[Mesh])

2. ("stress exposure"[Title/Abstract] OR "stress anticipati*"[Title/Abstract] OR "anticipatory stress"[Title/Abstract] OR "stress react*"[Title/Abstract] OR "stress recovery"[Title/Abstract] OR "stress habituat*"[Title/Abstract] OR "stress adaptat*"[Title/Abstract] OR "repeated stress"[Title/Abstract] OR "stress regulation"[Title/Abstract] OR "acute stress"[Title/Abstract] OR "physiological stress"[Title/Abstract] OR "psychological stress"[Title/Abstract] OR "self-reported stress"[Title/Abstract] OR "subjective stress"[Title/Abstract] OR "perceived stress" [Title/Abstract] OR "self-rated stress" [Title/Abstract] cortisol [Title/Abstract] OR "c-reactive protein"[Title/Abstract] OR "interleukin-6"[Title/Abstract] OR "heart rate"[Title/Abstract] OR "cardiovascular"[Title/Abstract] OR "blood pressure"[Title/Abstract] OR "norepinephrine"[Title/Abstract] OR "epinephrine"[Title/Abstract] OR "alpha-amylase"[Title/Abstract] OR "skin conductance" [Title/Abstract] OR glucorticoid*[Title/Abstract] OR "frequency spectral power"[Title/Abstract])

3. #1 & #2

4. Search ((("executive function*"[Title/Abstract] OR "executive control"[Title/Abstract] OR "cognitive function*"[Title/Abstract] OR "cognitive control"[Title/Abstract] OR "attention* control"[Title/Abstract] OR "inhibit*

control"[Title/Abstract] OR "behavior* inhibition"[Title/Abstract] OR "behaviour* inhibition"[Title/Abstract] OR "stroop"[Title/Abstract] OR "stop-signal"[Title/Abstract] OR "go/no-go"[Title/Abstract] OR "cognitive inhibition"[Title/Abstract] OR "cognitive flexibility"[Title/Abstract] OR "planning"[Title/Abstract] OR "shifting"[Title/Abstract] OR "switching"[Title/Abstract] OR "updating"[Title/Abstract] OR "working memory"[Title/Abstract] OR "fluency"[Title/Abstract] OR "selective attention"[Title/Abstract]))) AND (modification[Title/Abstract] OR training[Title/Abstract] OR program[Title/Abstract] OR intervention[Title/Abstract]) Filters: Humans

5. #2 & #4

Scopus

1. ((TITLE-ABS ("Executive control" OR "Cognitive function" OR "behavioral inhibition" OR "cognitive inhibition" OR "behavioural inhibition" OR stroop OR "go/no-go" OR "stop-signal" OR switching OR shifting OR flexibility OR planning OR updating OR fluency OR "inhibitory control" OR "executive function" OR "cognitive control" OR "working memory" OR "attentional control" OR "selective attention"))) AND ((TITLE-ABS (("stress exposure" OR "stress anticipati*" OR "anticipatory stress" OR "stress react*" OR "stress recovery"))) AND (EXCLUDE (SRCTYPE , "d") OR EXCLUDE (SRCTYPE , "b") OR EXCLUDE (SRCTYPE , "r") OR EXCLUDE (SRCTYPE , "Undefined")) AND (EXCLUDE (DOCTYPE , "ch") OR EXCLUDE (DOCTYPE , "sh") OR EXCLUDE (DOCTYPE , "no") OR EXCLUDE (DOCTYPE , "er") OR EXCLUDE (DOCTYPE , "bk") OR EXCLUDE (DOCTYPE , "ed") OR EXCLUDE (DOCTYPE , "le") OR EXCLUDE (DOCTYPE , "bz")) AND (EXCLUDE (SUBJAREA , "EART") OR EXCLUDE (SUBJAREA , "DECI")) AND (LIMIT-TO (LANGUAGE , "English")) AND (EXCLUDE (EXACTKEYWORD , "Nonhuman") OR EXCLUDE (EXACTKEYWORD , "Rat") OR EXCLUDE (EXACTKEYWORD , "Rats") OR EXCLUDE (EXACTKEYWORD , "Animal") OR EXCLUDE (EXACTKEYWORD , "Animals") OR EXCLUDE (EXACTKEYWORD , "Oral Drug Administration") OR EXCLUDE (EXACTKEYWORD , "Unclassified Drug") OR EXCLUDE (EXACTKEYWORD , "Drug Efficacy") OR EXCLUDE (EXACTKEYWORD , "Dipeptidyl Carboxypeptidase Inhibitor") OR EXCLUDE (EXACTKEYWORD , "Enzyme Inhibition") OR EXCLUDE (EXACTKEYWORD , "Acetylsalicylic Acid"))

2. ((TITLE-ABS ("Executive control" OR "Cognitive function" OR "behavioral inhibition" OR "cognitive inhibition" OR "behavioural inhibition" OR stroop OR "go/no-go" OR "stop-signal" OR switching OR shifting OR flexibility OR planning OR updating OR fluency OR "inhibitory control" OR "executive function" OR "cognitive control" OR "working memory" OR "attentional control" OR "selective attention"))) AND ((TITLE-ABS ("stress habituat*" OR "stress adaptat*" OR "repeated stress" OR "stress regulation" OR "acute stress""))) AND (EXCLUDE (SRCTYPE , "d") OR EXCLUDE (SRCTYPE , "b") OR EXCLUDE (SRCTYPE , "r") OR EXCLUDE (

SRCTYPE , "Undefined")) AND (EXCLUDE (DOCTYPE , "ch") OR EXCLUDE (DOCTYPE , "sh") OR EXCLUDE (DOCTYPE , "no") OR EXCLUDE (DOCTYPE , "er") OR EXCLUDE (DOCTYPE , "bk") OR EXCLUDE (DOCTYPE , "ed") OR EXCLUDE (DOCTYPE , "le") OR EXCLUDE (DOCTYPE , "bz")) AND (EXCLUDE (SUBJAREA , "EART") OR EXCLUDE (SUBJAREA , "DECI")) AND (LIMIT-TO (LANGUAGE , "English")) AND (EXCLUDE (EXACTKEYWORD , "Nonhuman") OR EXCLUDE (EXACTKEYWORD , "Rat") OR EXCLUDE (EXACTKEYWORD , "Rats") OR EXCLUDE (EXACTKEYWORD , "Animal") OR EXCLUDE (EXACTKEYWORD , "Animals") OR EXCLUDE (EXACTKEYWORD , "Oral Drug Administration") OR EXCLUDE (EXACTKEYWORD , "Unclassified Drug") OR EXCLUDE (EXACTKEYWORD , "Drug Efficacy") OR EXCLUDE (EXACTKEYWORD , "Dipeptidyl Carboxypeptidase Inhibitor") OR EXCLUDE (EXACTKEYWORD , "Enzyme Inhibition") OR EXCLUDE (EXACTKEYWORD , "Acetylsalicylic Acid"))

3. ((TITLE-ABS ("Executive control" OR "Cognitive function" OR "behavioral inhibition" OR "cognitive inhibition" OR "behavioural inhibition" OR stroop OR "go/no-go" OR "stop-signal" OR switching OR shifting OR flexibility OR planning OR updating OR fluency OR "inhibitory control" OR "executive function" OR "cognitive control" OR "working memory" OR "attentional control" OR "selective attention"))) AND ((TITLE-ABS ("physiological stress" OR "psychological stress" OR "self-reported stress" OR "subjective stress" OR “perceived stress” OR cortisol))) AND (EXCLUDE (SRCTYPE , "d") OR EXCLUDE (SRCTYPE , "b") OR EXCLUDE (SRCTYPE , "r") OR EXCLUDE (SRCTYPE , "Undefined")) AND (EXCLUDE (DOCTYPE , "ch") OR EXCLUDE (DOCTYPE , "sh") OR EXCLUDE (DOCTYPE , "no") OR EXCLUDE (DOCTYPE , "er") OR EXCLUDE (DOCTYPE , "bk") OR EXCLUDE (DOCTYPE , "ed") OR EXCLUDE (DOCTYPE , "le") OR EXCLUDE (DOCTYPE , "bz")) AND (EXCLUDE (SUBJAREA , "EART") OR EXCLUDE (SUBJAREA , "DECI")) AND (LIMIT-TO (LANGUAGE , "English")) AND (EXCLUDE (EXACTKEYWORD , "Nonhuman") OR EXCLUDE (EXACTKEYWORD , "Rat") OR EXCLUDE (EXACTKEYWORD , "Rats") OR EXCLUDE (EXACTKEYWORD , "Animal") OR EXCLUDE (EXACTKEYWORD , "Animals") OR EXCLUDE (EXACTKEYWORD , "Oral Drug Administration") OR EXCLUDE (EXACTKEYWORD , "Unclassified Drug") OR EXCLUDE (EXACTKEYWORD , "Drug Efficacy") OR EXCLUDE (EXACTKEYWORD , "Dipeptidyl Carboxypeptidase Inhibitor") OR EXCLUDE (EXACTKEYWORD , "Enzyme Inhibition") OR EXCLUDE (EXACTKEYWORD , "Acetylsalicylic Acid"))

4. ((TITLE-ABS ("Executive control" OR "Cognitive function" OR "behavioral inhibition" OR "cognitive inhibition" OR "behavioural inhibition" OR stroop OR "go/no-go" OR "stop-signal" OR switching OR shifting OR flexibility OR planning OR updating OR fluency OR "inhibitory control" OR "executive function" OR "cognitive control" OR "working memory" OR "attentional control" OR "selective attention"))) AND ((TITLE-ABS ("c-reactive protein" OR "interleukin-6"))) AND (EXCLUDE (

SRCTYPE , "d") OR EXCLUDE (SRCTYPE , "b") OR EXCLUDE (SRCTYPE , "r") OR EXCLUDE (SRCTYPE , "Undefined")) AND (EXCLUDE (DOCTYPE , "ch") OR EXCLUDE (DOCTYPE , "sh") OR EXCLUDE (DOCTYPE , "no") OR EXCLUDE (DOCTYPE , "er") OR EXCLUDE (DOCTYPE , "bk") OR EXCLUDE (DOCTYPE , "ed") OR EXCLUDE (DOCTYPE , "le") OR EXCLUDE (DOCTYPE , "bz")) AND (EXCLUDE (SUBJAREA , "EART") OR EXCLUDE (SUBJAREA , "DECI")) AND (LIMIT-TO (LANGUAGE , "English")) AND (EXCLUDE (EXACTKEYWORD , "Nonhuman") OR EXCLUDE (EXACTKEYWORD , "Rat") OR EXCLUDE (EXACTKEYWORD , "Rats") OR EXCLUDE (EXACTKEYWORD , "Animal") OR EXCLUDE (EXACTKEYWORD , "Animals") OR EXCLUDE (EXACTKEYWORD , "Oral Drug Administration") OR EXCLUDE (EXACTKEYWORD , "Unclassified Drug") OR EXCLUDE (EXACTKEYWORD , "Drug Efficacy") OR EXCLUDE (EXACTKEYWORD , "Dipeptidyl Carboxypeptidase Inhibitor") OR EXCLUDE (EXACTKEYWORD , "Enzyme Inhibition") OR EXCLUDE (EXACTKEYWORD , "Acetylsalicylic Acid"))

5. ((TITLE-ABS ("Executive control" OR "Cognitive function" OR "behavioral inhibition" OR "cognitive inhibition" OR "behavioural inhibition" OR stroop OR "go/no-go" OR "stop-signal" OR switching OR shifting OR flexibility OR planning OR updating OR fluency OR "inhibitory control" OR "executive function" OR "cognitive control" OR "working memory" OR "attentional control" OR "selective attention"))) AND ((TITLE-ABS ("heart rate"))) AND (EXCLUDE (SRCTYPE , "d") OR EXCLUDE (SRCTYPE , "b") OR EXCLUDE (SRCTYPE , "r") OR EXCLUDE (SRCTYPE , "Undefined")) AND (EXCLUDE (DOCTYPE , "ch") OR EXCLUDE (DOCTYPE , "sh") OR EXCLUDE (DOCTYPE , "no") OR EXCLUDE (DOCTYPE , "er") OR EXCLUDE (DOCTYPE , "bk") OR EXCLUDE (DOCTYPE , "ed") OR EXCLUDE (DOCTYPE , "le") OR EXCLUDE (DOCTYPE , "bz")) AND (EXCLUDE (SUBJAREA , "EART") OR EXCLUDE (SUBJAREA , "DECI")) AND (LIMIT-TO (LANGUAGE , "English")) AND (EXCLUDE (EXACTKEYWORD , "Nonhuman") OR EXCLUDE (EXACTKEYWORD , "Rat") OR EXCLUDE (EXACTKEYWORD , "Rats") OR EXCLUDE (EXACTKEYWORD , "Animal") OR EXCLUDE (EXACTKEYWORD , "Animals") OR EXCLUDE (EXACTKEYWORD , "Oral Drug Administration") OR EXCLUDE (EXACTKEYWORD , "Unclassified Drug") OR EXCLUDE (EXACTKEYWORD , "Drug Efficacy") OR EXCLUDE (EXACTKEYWORD , "Dipeptidyl Carboxypeptidase Inhibitor") OR EXCLUDE (EXACTKEYWORD , "Enzyme Inhibition") OR EXCLUDE (EXACTKEYWORD , "Acetylsalicylic Acid"))

6. ((TITLE-ABS ("Executive control" OR "Cognitive function" OR "behavioral inhibition" OR "cognitive inhibition" OR "behavioural inhibition" OR stroop OR "go/no-go" OR "stop-signal" OR switching OR shifting OR flexibility OR planning OR updating OR fluency OR "inhibitory control" OR "executive function" OR "cognitive control" OR "working memory" OR "attentional control" OR "selective attention"))) AND ((TITLE-ABS (cardiovascular))) AND (EXCLUDE (SRCTYPE , "d") OR

EXCLUDE (SRCTYPE , "b") OR EXCLUDE (SRCTYPE , "r") OR EXCLUDE (SRCTYPE , "Undefined")) AND (EXCLUDE (DOCTYPE , "ch") OR EXCLUDE (DOCTYPE , "sh") OR EXCLUDE (DOCTYPE , "no") OR EXCLUDE (DOCTYPE , "er") OR EXCLUDE (DOCTYPE , "bk") OR EXCLUDE (DOCTYPE , "ed") OR EXCLUDE (DOCTYPE , "le") OR EXCLUDE (DOCTYPE , "bz")) AND (EXCLUDE (SUBJAREA , "EART") OR EXCLUDE (SUBJAREA , "DECI")) AND (LIMIT-TO (LANGUAGE , "English")) AND (EXCLUDE (EXACTKEYWORD , "Nonhuman") OR EXCLUDE (EXACTKEYWORD , "Rat") OR EXCLUDE (EXACTKEYWORD , "Rats") OR EXCLUDE (EXACTKEYWORD , "Animal") OR EXCLUDE (EXACTKEYWORD , "Animals") OR EXCLUDE (EXACTKEYWORD , "Oral Drug Administration") OR EXCLUDE (EXACTKEYWORD , "Unclassified Drug") OR EXCLUDE (EXACTKEYWORD , "Drug Efficacy") OR EXCLUDE (EXACTKEYWORD , "Dipeptidyl Carboxypeptidase Inhibitor") OR EXCLUDE (EXACTKEYWORD , "Enzyme Inhibition") OR EXCLUDE (EXACTKEYWORD , "Acetylsalicylic Acid")) AND (EXCLUDE (SUBJAREA , "BUSI") OR EXCLUDE (SUBJAREA , "CENG") OR EXCLUDE (SUBJAREA , "CHEM") OR EXCLUDE (SUBJAREA , "COMP") OR EXCLUDE (SUBJAREA , "DENT") OR EXCLUDE (SUBJAREA , "ECON") OR EXCLUDE (SUBJAREA , "ENER")) AND (EXCLUDE (SRCTYPE , "k")) AND (EXCLUDE (SUBJAREA , "ENGI") OR EXCLUDE (SUBJAREA , "ENVI") OR EXCLUDE (SUBJAREA , "IMMU") OR EXCLUDE (SUBJAREA , "MATE") OR EXCLUDE (SUBJAREA , "MATH")) AND (EXCLUDE (SUBJAREA , "PHAR") OR EXCLUDE (SUBJAREA , "PHYS") OR EXCLUDE (SUBJAREA , "AGRI") OR EXCLUDE (SUBJAREA , "ARTS") OR EXCLUDE (SUBJAREA , "VETE")) AND (EXCLUDE (EXACTKEYWORD , "Smoking"))

7. ((TITLE-ABS ("Executive control" OR "Cognitive function" OR "behavioral inhibition" OR "cognitive inhibition" OR "behavioural inhibition" OR stroop OR "go/no-go" OR "stop-signal" OR switching OR shifting OR flexibility OR planning OR updating OR fluency OR "inhibitory control" OR "executive function" OR "cognitive control" OR "working memory" OR "attentional control" OR "selective attention"))) AND ((TITLE-ABS ("blood pressure"))) AND (EXCLUDE (SRCTYPE , "d") OR EXCLUDE (SRCTYPE , "b") OR EXCLUDE (SRCTYPE , "r") OR EXCLUDE (SRCTYPE , "Undefined")) AND (EXCLUDE (DOCTYPE , "ch") OR EXCLUDE (DOCTYPE , "sh") OR EXCLUDE (DOCTYPE , "no") OR EXCLUDE (DOCTYPE , "er") OR EXCLUDE (DOCTYPE , "bk") OR EXCLUDE (DOCTYPE , "ed") OR EXCLUDE (DOCTYPE , "le") OR EXCLUDE (DOCTYPE , "bz")) AND (EXCLUDE (SUBJAREA , "EART") OR EXCLUDE (SUBJAREA , "DECI")) AND (LIMIT-TO (LANGUAGE , "English")) AND (EXCLUDE (EXACTKEYWORD , "Nonhuman") OR EXCLUDE (EXACTKEYWORD , "Rat") OR EXCLUDE (EXACTKEYWORD , "Rats") OR EXCLUDE (EXACTKEYWORD , "Animal") OR EXCLUDE (EXACTKEYWORD , "Animals") OR EXCLUDE (EXACTKEYWORD , "Oral Drug Administration") OR EXCLUDE (EXACTKEYWORD , "Unclassified Drug") OR EXCLUDE (EXACTKEYWORD , "Drug Efficacy") OR EXCLUDE (EXACTKEYWORD ,

"Dipeptidyl Carboxypeptidase Inhibitor") OR EXCLUDE (EXACTKEYWORD , "Enzyme Inhibition") OR EXCLUDE (EXACTKEYWORD , "Acetylsalicylic Acid")) AND (EXCLUDE (SUBJAREA , "COMP") OR EXCLUDE (SUBJAREA , "PHYS") OR EXCLUDE (SUBJAREA , "CENG") OR EXCLUDE (SUBJAREA , "MATE") OR EXCLUDE (SUBJAREA , "ENVI") OR EXCLUDE (SUBJAREA , "IMMU") OR EXCLUDE (SUBJAREA , "MATH") OR EXCLUDE (SUBJAREA , "BUSI") OR EXCLUDE (SUBJAREA , "DENT") OR EXCLUDE (SUBJAREA , "CHEM") OR EXCLUDE (SUBJAREA , "ENER") OR EXCLUDE (SUBJAREA , "VETE") OR EXCLUDE (SUBJAREA , "ECON")) AND (EXCLUDE (EXACTKEYWORD , "Antihypertensive Agent") OR EXCLUDE (EXACTKEYWORD , "Smoking"))

8. ((TITLE-ABS ("Executive control" OR "Cognitive function" OR "behavioral inhibition" OR "cognitive inhibition" OR "behavioural inhibition" OR stroop OR "go/no-go" OR "stop-signal" OR switching OR shifting OR flexibility OR planning OR updating OR fluency OR "inhibitory control" OR "executive function" OR "cognitive control" OR "working memory" OR "attentional control" OR "selective attention"))) AND ((TITLE-ABS ("norepinephrine" OR "epinephrine" OR "alpha-amylase" OR "skin conductance" OR glucorticoid* OR "frequency spectral power"))) AND (EXCLUDE (SRCTYPE , "d") OR EXCLUDE (SRCTYPE , "b") OR EXCLUDE (SRCTYPE , "r") OR EXCLUDE (SRCTYPE , "Undefined")) AND (EXCLUDE (DOCTYPE , "ch") OR EXCLUDE (DOCTYPE , "sh") OR EXCLUDE (DOCTYPE , "no") OR EXCLUDE (DOCTYPE , "er") OR EXCLUDE (DOCTYPE , "bk") OR EXCLUDE (DOCTYPE , "ed") OR EXCLUDE (DOCTYPE , "le") OR EXCLUDE (DOCTYPE , "bz")) AND (EXCLUDE (SUBJAREA , "EART") OR EXCLUDE (SUBJAREA , "DECI")) AND (LIMIT-TO (LANGUAGE , "English")) AND (EXCLUDE (EXACTKEYWORD , "Nonhuman") OR EXCLUDE (EXACTKEYWORD , "Rat") OR EXCLUDE (EXACTKEYWORD , "Rats") OR EXCLUDE (EXACTKEYWORD , "Animal") OR EXCLUDE (EXACTKEYWORD , "Animals") OR EXCLUDE (EXACTKEYWORD , "Oral Drug Administration") OR EXCLUDE (EXACTKEYWORD , "Unclassified Drug") OR EXCLUDE (EXACTKEYWORD , "Drug Efficacy") OR EXCLUDE (EXACTKEYWORD , "Dipeptidyl Carboxypeptidase Inhibitor") OR EXCLUDE (EXACTKEYWORD , "Enzyme Inhibition") OR EXCLUDE (EXACTKEYWORD , "Acetylsalicylic Acid")) AND (EXCLUDE (SUBJAREA , "COMP") OR EXCLUDE (SUBJAREA , "PHYS") OR EXCLUDE (SUBJAREA , "CENG") OR EXCLUDE (SUBJAREA , "MATE") OR EXCLUDE (SUBJAREA , "ENVI") OR EXCLUDE (SUBJAREA , "IMMU") OR EXCLUDE (SUBJAREA , "MATH") OR EXCLUDE (SUBJAREA , "BUSI") OR EXCLUDE (SUBJAREA , "DENT") OR EXCLUDE (SUBJAREA , "CHEM") OR EXCLUDE (SUBJAREA , "ENER") OR EXCLUDE (SUBJAREA , "VETE") OR EXCLUDE (SUBJAREA , "ECON")) AND (EXCLUDE (EXACTKEYWORD , "Antihypertensive Agent") OR EXCLUDE (EXACTKEYWORD , "Smoking"))

9. ((((TITLE-ABS ("Executive control" OR "Cognitive function" OR "behavioral inhibition" OR "cognitive inhibition" OR "behavioural inhibition" OR stroop OR "go/no-go" OR "stop-signal" OR switching OR shifting OR flexibility OR planning OR updating OR fluency OR "inhibitory control" OR "executive function" OR "cognitive control" OR "working memory" OR "attentional control" OR "selective attention")) W/2 (intervention OR modification OR program OR training)))) AND ((TITLE-ABS ("Stress exposure" OR "stress anticipation" OR "anticipatory stress" OR "stress reactivity" OR "stress recovery" OR "stress habituation" OR "stress adaptation" OR "repeated stress" OR "stress adaptation" OR "stress regulation" OR "subjective stress" OR "perceived stress" OR "psychological stress" OR "physiological stress" OR "cortisol" OR "self-reported stress" OR "self-rated stress" OR "subjective stress" OR "c-reactive protein" OR "interleukin-6" OR noradrenaline OR norepinephrine OR "epinephrine" OR "blood pressure" OR "alpha-amylase" OR "cardiovascular" OR "skin conductance" OR "frequency spectral power" OR "heart rate" OR "acute stress" OR glucorticoid))) AND (EXCLUDE (SRCTYPE , "d") OR EXCLUDE (SRCTYPE , "b") OR EXCLUDE (SRCTYPE , "r") OR EXCLUDE (SRCTYPE , "Undefined")) AND (EXCLUDE (DOCTYPE , "ch") OR EXCLUDE (DOCTYPE , "sh") OR EXCLUDE (DOCTYPE , "no") OR EXCLUDE (DOCTYPE , "er") OR EXCLUDE (DOCTYPE , "bk") OR EXCLUDE (DOCTYPE , "ed") OR EXCLUDE (DOCTYPE , "le") OR EXCLUDE (DOCTYPE , "bz")) AND (EXCLUDE (SUBJAREA , "EART") OR EXCLUDE (SUBJAREA , "DECI")) AND (LIMIT-TO (LANGUAGE , "English")) AND (EXCLUDE (EXACTKEYWORD , "Nonhuman") OR EXCLUDE (EXACTKEYWORD , "Rat") OR EXCLUDE (EXACTKEYWORD , "Rats") OR EXCLUDE (EXACTKEYWORD , "Animal") OR EXCLUDE (EXACTKEYWORD , "Animals") OR EXCLUDE (EXACTKEYWORD , "Oral Drug Administration") OR EXCLUDE (EXACTKEYWORD , "Unclassified Drug") OR EXCLUDE (EXACTKEYWORD , "Drug Efficacy") OR EXCLUDE (EXACTKEYWORD , "Dipeptidyl Carboxypeptidase Inhibitor") OR EXCLUDE (EXACTKEYWORD , "Enzyme Inhibition") OR EXCLUDE (EXACTKEYWORD , "Acetylsalicylic Acid"))

Web of Science

1. ((TS=("Executive control" OR "Cognitive function" OR "behavioral inhibition" OR "cognitive inhibition" OR "behavioural inhibition" OR stroop OR "go/no-go" OR "stop-signal" OR switching OR shifting OR flexibility OR planning OR updating OR fluency OR "inhibitory control" OR "executive function" OR "cognitive control" or "working memory" or "attentional control" OR "selective attention"))) AND LANGUAGE: (English) AND DOCUMENT TYPES: (Article) Indexes=SCI-EXPANDED, SSCI, A&HCI, ESCI Timespan=All years

2. (TS=("Stress exposure" OR "stress anticipation" OR "anticipatory stress" OR "stress reactivity" OR "stress recovery" OR "stress habituation" OR "stress adaptation" OR "repeated stress" OR "stress adaptation" OR "stress regulation" OR "subjective stress" OR

"perceived stress" OR "psychological stress" OR "physiological stress" OR "cortisol" OR "self-reported stress" OR "self-rated stress" OR "subjective stress" OR "c-reactive protein" OR"interleukin-6" OR noradrenaline OR norepinephrine OR "epinephrine" OR "blood pressure" OR "alpha-amylase" OR "cardiovascular" OR "skin conductance" OR "frequency spectral power" OR "heart rate" OR "acute stress" OR glucorticoid)) AND LANGUAGE: (English) AND DOCUMENT TYPES: (Article)

3. #1 and #2 Indexes=SCI-EXPANDED, SSCI, A&HCI, ESCI Timespan=All years

4. ((TS=((("Executive control" OR "Cognitive function*" OR "behavioral inhibition" OR "cognitive inhibition" OR "behavioural inhibition" OR stroop OR "go/no-go" OR "stop-signal"OR switching OR shifting OR flexibility OR planning OR updating OR fluency OR "inhibitory control" OR "executive function*" OR "cognitive control" OR "working memory" OR "attention* control" OR "selective attention") NEAR (intervention OR modification OR program OR training))))) AND LANGUAGE: (English) AND DOCUMENT TYPES: (Article)

5. #2 and #4

B.3 Quality Appraisal Scales for Correlational Design

Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies (National Heart, Lung, and Blood Institute, NHLBI, 2021)

The NHLBI tool requires reviewers to answer each of the 14 questions using "yes", "no", or "other" ("cannot determine", "not reported", or "not applicable"). Ultimately, this leads to attributing to each study the label of "good", "fair", or "poor" quality, based on its potential flaws in design or implementation. For the purpose of this systematic literature review, we retained the scale items in Table 24.

Quality Appraisal Tool for Cross-sectional Studies using Biomarker Data (BIOCROSS; (Wirsching et al., 2018)

The Biomarker Measurement domain of the BIOCROSS tool comprises three subscales evaluating specimen characteristics and assay methods, laboratory measurement, and biomarker data modelling, not otherwise present in the NIH tool. Reviewers attribute a score of "2" when all items on the list have been mentioned, a score of "1" when one or two items are missing, and a score of "0" when none of the items has been mentioned.

Table 24. NHLBI Tool

Question	Response Options
1. Was the research question or objective in this paper clearly stated?	Yes/ No/ Other (Cannot Determine, Not reported, Not applicable)
2. Was the study population clearly specified and defined?	
3. Was the participation rate of eligible persons at least 50%?	
4. Were inclusion and exclusion criteria for being in the study prespecified and applied uniformly to all participants?	
5. Was a sample size justification, power description, or variance and effect estimates provided?	
6. For the analyses in this paper, were the exposure(s) of interest measured prior to the outcome(s) being measured?	
7. Were the exposure measures (independent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?	
8. Were the outcome measures (dependent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?	
[For studies with several sessions only] 9. Was loss to follow-up after baseline 20% or less?	
10. Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)?	

Table 25. BIOCROSS Subscale

Study Quality Feature	Question	Response Options
Biomarker measurement: Specimen characteristics and assay methods	11. Were the measurement methods described? (assay methods, preservation and storage, detailed protocol, including specific reagents or kits used)	
	12. Were the reproducibility assessments performed for evaluating biomarker stability?	
	13. Were the quantitation methods well described?	
Biomarker measurement: Laboratory measurement	14. Was the laboratory/place of measurement mentioned?	2: All items mentioned 1: One or two items missing 0: None of the items mentioned
	15. Were any quality control procedures and results reported (e.g., reported coefficient of variation?	
	16. Were the analyses blinded for laboratory staff?	
Biomarker measurement: Biomarker data modeling	17. Was the distribution of biomarker data reported (if non-normal how it was standardized)?	
	18. Did the authors report on methods or outlier detection and handling?	
	19. Were any possible errors resulting from measurement inaccuracies discussed?	

Appendix C:
Supplementary Materials from Chapter 3

C.1 Measures

Questionnaires

Chronic stress (original validation study: Cohen et al., 1994)

Participants rated their responses on a scale from 0 (never) to 4 (very often) for 10 items, with 4 items reverse-scored. The total score corresponded to the sum of all items, with higher scores reflecting greater stress.

Anxiety (original validation study: Spitzer et al., 2006)

Individuals were asked to indicate the frequency with which they felt troubled by seven anxiety-related symptoms over the last two weeks, on a scale ranging from 0 (never) to 3 (almost every day). The outcome was the sum of all seven items.

Depression (original validation study: Lewinsohn et al., 1997)

The scale requires participants to indicate the frequency with which they experienced feelings and behaviors over the previous week. Items are answered on a Likert scale ranging from 0 [Never/Very rarely (less than a day)] to 3 [Frequently/All the time (5-7 days)]. Depressive symptom severity was calculated by summing the scores of all items, after reversing four.

Covid-related stress

Adapted from the PSS-10, this questionnaire is composed of five items relating to feelings and thoughts about the Coronavirus pandemic. Participants must indicate the frequency with which each item has occurred over the last month, on a Likert scale ranging from 0 (never) to 4 (very often).

Primary appraisal (original validation: Peacock & Wong, 1990)

Participants were asked to think about the upcoming exams and to rate the extent to which 28 items were relevant to them, on a scale ranging from 1 (not at all) to 5 (extremely). In the original version (Peacock & Wong, 1990), the questionnaire generates seven outcomes, namely threat, challenge, centrality, controllable by the self, controllable by others, and uncontrollable by anyone. However, several validation studies have repeatedly noted low Cronbach's α coefficients for some of these scales. In the French validation version, the exploratory factor analyses revealed that a five-factor solution would be better suited, with the "primary appraisal" subscale combining items from both challenge and threat.

Coping (Original version: Carver, 1997)

Participants specified the extent to which they applied 28 coping strategies ahead of the examination period, using a Likert scale ranging from 1 (I haven't been doing this at all) to 4 (I have been doing this a lot).

Anticipatory repetitive negative thinking

At Time 2, participants indicated the extent to which 22 items were true with respect to their upcoming examination session. All items scored on a scale from 1 (not true at all) to 5 (completely true).

Worry (original validation study: Meyer et al., 1990)

The questionnaire comprises 16 items, each rated on a Likert-type scale ranging from 1 (not at all typical of me) to 5 (very typical of me). Participants were asked to indicate the extent to which each statement reflects their own current experiences and thoughts.

Cognitive Tasks

Inhibition

On each trial, a fixation circle appeared at the center of the computer screen, within which an arrow pointing left or right would appear within this circle. The task was to indicate the direction (left or right) towards which the arrow was pointing, using the "D" and "K" keys, respectively. Participants were specifically reminded to respond as quickly as possible without waiting for the stop signal to occur, explaining that otherwise the computer would further delay the presentation otherwise. On certain occasions, participants heard a beep in their headphones, indicating that they were to omit from responding on that trial. The total task comprised four blocks of 64 trials, where the arrows pointed left half of the time and right the other half. The chosen direction of the arrow was randomized for each trial. The initial Stop Signal Delay was set at 300ms and was adjusted up or down by increments of 50s depending upon successful (i.e., increased) or unsuccessful (i.e., decreased) performance. The minimum and maximum delays were 50ms and 1250ms, respectively. The ratio for signal to no-signal trials was set at 1:3 and the target response inhibition probability at 0.5. Each trial (signal or no-signal) lasted 2000ms and was preceded by a pre-trial pause of 750ms. Participants were also presented with a 15-second pause between each block, during which the instructions were presented again as a reminder. The test blocks were preceded by one practice block of 32 trials, also showing 25% signal trials (i.e., 8 signals). The first trial in each test block was not analyzed (Verbruggen et al., 2008). The mean stop signal delay in the final sample was 375.39ms (SD = 160.23), the SSRT was 184.63ms (SD = 42.77), mean reaction time of go responses on unsuccessful stop signals was 492.65ms (SD = 107.30), and the mean reaction time of correct go responses on no-signal trials was 565.74ms (SD = 121.50).

Cognitive flexibility

A 2x2 quadrant was presented on the computer screen. On each new trial, a letter-number pair (e.g., "7G") appeared in one of the quadrants, moving in clockwise fashion to the next box. Participants responded to one of two categorization tasks depending on the position of the pair on the screen. If the pair appeared on the top of the screen, participants indicated whether the letter was a consonant or a vowel (i.e., Letter Task), using the "E" and "I" keys, respectively. If the pair appeared on the two lower quadrants, participants indicated whether the number in the pair was even ("E") or odd ("I"). The task began with two practice blocks, during which the participants first completed 32 separate trials of the letter and number tasks, where the numbers appeared only on the top or bottom quadrants, accordingly. The test portion of the task consisted of 128 trials (64 switch trials, 64 non-switch trials) where the participants completed the two tasks simultaneously. It was preceded by a combined practice block of 16 trials. The stimuli disappeared 150ms after the response if the latter was correct, and after 1500ms if not.

Working memory updating

Participants were presented with a fixation cross for 100ms, followed by single letters at the center of the computer screen. For each new letter, they named the last three letters they had seen, after which they selected the letters on a letter matrix using the mouse. The letters appeared onscreen for 2500ms each. Each letter set was composed of five, seven, or nine letters. The practice block presented three trials (one for each set size) in random order. The test block had 12 trials (four blocks of each set size) with the order randomized but ensuring that each set size appeared once every three trials.

Working memory

In the letter memory part, participants were presented with sequences of individual letters, with spans ranging from three to seven. Following the initial presentation, participants were to recall as many as possible in the correct order as was presented using their mouse and an onscreen letter matrix. Between letter trials, participants were presented with a simple addition, subtraction, multiplication, or division problem, as well as a possible solution. Participants were asked to decide whether the proposed solution was correct by using their mouse to select yes or no. The practice block comprised (a) four trials of recalling letter spans (with set sizes of two to three in ascending order), (b) 15 trials of the mathematical task, and (c) three trials of the combined tasks (letter set size of two and one math problem). The test block was composed of 15 trials, in which the five set sizes were repeated three times each, and the order of presentation of the set sizes randomized, leading to a total of 75 mathematical problems and letters.

Planning

Participants completed one practice trial consisting of a problem requiring two moves. The test comprised 12 problems, two problems requiring two and three moves, as well as four problems requiring four and five moves. There were no time limits, but the participants had three attempts to solve the problem using the maximum number of moves, after which they would be forwarded to the next challenge. The problems were presented sequentially in a fixed, increasing order.

C.2 Results

Descriptive Statistics

Regarding sociodemographic variables, the excluded participants (N = 20) displayed a significant gender disparity, X^2 (1, N =153) = 8.96, p = .015. Specifically, the excluded group comprised 11 women and 9 men, while the included participants consisted of 106 women and 27 men.

With respect to correlational analyses, gender correlated significantly with anticipatory RNT [r(131)=.20, p = 0.20], worry [r(131) = .39, p <.001], examination stress [r(131) = .22, p=.012], and chronic stress at baseline [r(131) = .24, p = .005] (see Table S2 for an overview of the correlations between all variables). Better flexibility (i.e., lower switch costs) was also associated with lower maladaptive coping [ρ (131) = .26, p=.003]. Delving into the coping subscales, higher switch costs were associated with greater substance use [ρ(131) = .24, p = .006] and lower acceptance of the situation [ρ(131) = -.27, p = .001] (see Table S3). Higher fluency scores correlated with less worry [r(131) = -.18, p=.042] and less chronic stress at baseline [r(131) = -.18, p=.0.41]. Updating, on the other hand, correlated significantly with higher use of self-blame [ρ(131) = .19, p = .030]. Higher planning scores were significantly associated with less worry [ρ(131) = -.24, p =.006], lower examination stress [ρ(131) = -.18, p =.043], as well as lower use of instrumental [ρ(131) = -.20, p =.021], and emotional support [ρ(131) = -.26, p =.003] (see Table S3).

Challenge appraisals [r(131) = -.42, p <.001], maladaptive coping [r(131) = .32, p <.001], anticipatory RNT [r(131) = .60, p <.001], worry [r(131) = .56, p <.001], chronic stress at Time 1 [r(131) = .51, p <.001], and Covid-related stress at Time 2 [r(131) = .61, p <.001], were also significantly associated with anticipatory stress.

C.3 Supplementary Tables

Supplementary Table S1. *Correlations between Chronic Stress, Anxiety and Depression Scores*

	Chronic Stress	Anxiety	Depression
Anxiety	**.68*** **	-	
Depression	**.68*** **	**.65*** **	-
Covid-related Stress	**.54*** **	**.45*** **	**.42*** **

Note. *N* = 133. *All significant correlations are represented in bold. ***p < .001.*

Supplementary Table S2. *Results from the Multiple Regression Model with Examination Stress as an Outcome*

	Standardized Beta Coefficients	*t*	p-value
Inhibition (SSRT)	-.07	-1.12	.265
Flexibility (Switch Costs)	.07	1.04	.303
Flexibility (Verbal Fluency)	.00	-.04	.971
Updating (Proportion Correct of Letters Recalled)	.03	.45	.655
Working Memory (OSpan Score)	-.04	-.62	.534
Planning (Total Score)	.03	.39	.694
Challenge/Threat	**-.15**	**-1.98**	**.050**
Adaptive Coping	.05	.79	.428
Maladaptive Coping	-.09	-1.03	.307
Anticipatory Repetitive Negative Thinking	**.39**	**3.93**	**<.001**
Worry	.04	.40	.690
Gender	.06	.93	.355
Chronic Stress	.03	.29	.775
Covid Stress	**.40**	**5.09**	**<.001**

Note. *N* = 133; Significant predictors are presented in bold: *p ≤ .05, **p ≤ .010, ***p < .001; R2 = .573; F(14,118)=11.32, p<.001; Gender was coded 1 (male) and 2 (female); SSRT = Stop Signal Reaction Time (ms); OSpan = Operation Span.

Supplementary Table S3. Results from the Multiple Regression Model with Challenge/Threat as an Outcome

	Standardized Beta Coefficients	*t*	p-value
Inhibition (SSRT)	-.02	-.21	.838
Flexibility (Switch Costs)	-.06	-.77	.444
Flexibility (Verbal Fluency)	-.10	-1.14	.258
Updating (Proportion Correct of Letters Recalled)	.16	1.65	.102
Working Memory (OSpan Score)	.07	.78	.434
Planning (Total Score)	.00	.04	.971
Gender	**.18**	**2.13**	**.036**
Chronic Stress	**-.38**	**-4.41**	**<.001**

Note. *N* = 133; Significant predictors are presented in bold: *p ≤ .05, **p ≤ .010, ***p < .001; R2= 0.13; F(8,124)=3.41, p=.001; Gender was coded 1 (male) and 2 (female); SSRT = Stop Signal Reaction Time (ms); OSpan = Operation Span.

Supplementary Table S4. Correlations between Planning (Executive Functioning) and all BRIEF-Cope Subscales

	Spearman Correlations with Planning (Total Score)	Spearman Correlations with Flexibility (Switch Costs)	Corresponding BRIEF-Cope Subscale	Cronbach Alpha
Active Coping	.05	-.06	Adaptive	.61
Acceptance	.02	**-.27****	Adaptive	.56
Planning	.06	-.13	Adaptive	.74
Use of Instrumental Support	**-.20***	.00	Adaptive	.86
Use of Emotional Support	**-.26****	.02	Adaptive	.89
Emotional Expression	-.14	-.07	Adaptive	.67
Positive Reframing	.03	-.03	Adaptive	.71
Denial	-.02	.17	Maladaptive	.64
Substance Use	-.09	**.24****	Maladaptive	.91
Behavioral Disengagement	.04	.10	Maladaptive	.79
Self-blame	-.04	.14	Maladaptive	.51
Self-distraction	-.10	.16	Maladaptive	.53

Note. *N = 133; Significant correlations are represented in bold: *p ≤ .05, **p ≤ .010, ***p < .001.*

Supplementary Table S5. Correlations between all Study Variables (*N* = 133)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Age	-															
2. Gender	**-0.24****	-														
3. Years of education	**0.71*****	-0.11	-													
4. Inhibition (SSRT)	0.05	-0.04	-0.07	-												
5. Flexibility (Switch Cost)	0.10	0.002	0.06	0.03	-											
6. Flexibility (Fluency)	**0.18***	-0.07	0.13	0.04	-0.16	-										
7. Updating (Proportion Correct of Letters Recalled)	0.001	-0.14	0.04	**0.20***	-0.07	0.17	-									
8. Working Memory (OSpan Score)	-0.01	-0.12	0.16	-0.13	0.05	**0.18***	**0.39*****	-								
9. Planning (Total Score)	-0.05	-0.03	-0.07	0.17	-0.06	-0.08	**0.23****	0.13	-							
10. Challenge and Threat Appraisal	0.02	0.06	-0.02	-0.01	-0.09	0.01	0.09	0.12	0.09	-						
11. Anticipatory Repetitive Negative Thinking	-0.12	**0.20***	-0.02	0.07	0.10	-0.11	0.03	-0.03	-0.14	**-0.40*****	-					
12. Worry	-0.08	**0.39*****	-0.03	-0.04	0.05	**-0.18***	-0.14	-0.13	**-0.24****	**-0.32*****	**0.65*****	-				
13. Adaptive Coping	-0.14	0.11	-0.08	0.002	-0.13	-0.06	-0.08	-0.07	**-0.10***	**0.26****	0.13	**0.18***	-			
14. Maladaptive Coping	0.04	0.06	0.11	0.05	**0.26****	-0.04	0.06	-0.001	-0.08	**-0.39*****	**0.56*****	**0.24****	**-0.19***	-		
15. Examination stress	-0.07	**0.22***	0.07	-0.07	0.06	-0.09	-0.12	-0.11	**-0.18***	**-0.42*****	**0.60*****	**0.56*****	0.12	**0.32*****	-	
16. Chronic Stress	-0.01	**0.24****	0.08	-0.01	0.07	**-0.18***	-0.06	-0.05	-0.13	**-0.34*****	**0.51*****	**0.65*****	0.05	**0.26****	**0.51*****	-
17. Covid-related Stress	**-.18***	.16	-.02	-0.09	-0.04	-0.05	-0.16	-0.11	**-0.23****	**-0.36****	**0.37*****	**0.47*****	0.09	**0.23****	**0.61*****	**0.54*****

Note. *Significant correlations are represented in bold. *p ≤ .05, **p ≤ .010, ***p < .001; Gender was coded 1 (male) and 2 (female); SSRT = Stop Signal Reaction Time (ms); OSpan = Operation Span.*

Supplementary Table S6. Results from the Multiple Regression Model with Adaptive Coping as an Outcome

	Standardized Beta Coefficients	*t*	p-value
Inhibition (SSRT)	.05	.51	.613
Flexibility (Switch Costs)	-.11	-1.20	.232
Flexibility (Verbal Fluency)	-.07	-.72	.470
Updating (Proportion Correct of Letters Recalled)	.00	-.01	.988
Working Memory (OSpan Score)	-.01	-.06	.956
Planning (Total Score)	**-.20**	**-2.21**	**.029**
Gender	.10	1.08	.280
Chronic Stress	-.01	-.08	.932

Note. *N* = 133; Significant predictors are presented in bold: *p ≤ .05, **p ≤ .010, ***p < .001; R2= 0.06; F(8,124)=1.05, p=.405; Gender was coded 1 (male) and 2 (female); SSRT = Stop Signal Reaction Time (ms); OSpan = Operation Span.

Supplementary Table S7. Results from the Multiple Regression Model with Maladaptive Coping as an Outcome

	Standardized Beta Coefficients	*t*	p-value
Inhibition (SSRT)	-.01	-.07	.944
Flexibility (Switch Costs)	**.27**	**3.18**	**.002**
Flexibility (Verbal Fluency)	.02	.22	.829
Updating (Proportion Correct of Letters Recalled)	.16	1.66	.100
Working Memory (OSpan Score)	-.05	-.51	.612
Planning (Total Score)	-.02	-.21	.837
Gender	.03	.33	.742
Chronic Stress	**.29**	**3.31**	**.001**

Note. *N = 133* (the results without the two extreme standardized residuals are the same); Significant predictors are presented in bold: *p ≤ .05, **p ≤ .010, ***p < .001; R2 = .19; F(8,124)= 3.51, p=.001; Gender was coded 1 (male) and 2 (female); SSRT = Stop Signal Reaction Time (ms), OSpan = Operation Span.

Supplementary Table S8. Results from the Multiple Regression Model with Anticipatory Repetitive Negative Thinking as an Outcome

	Standardized Beta Coefficients	***t***	**p-value**
Inhibition (SSRT)	.10	1.19	.238
Flexibility (Switch Costs)	.03	.35	.725
Flexibility (Verbal Fluency)	-.03	-.39	.696
Updating (Proportion Correct of Letters Recalled)	.04	.50	.620
Working Memory (OSpan Score)	.01	.14	.887
Planning (Total Score)	-.11	-1.38	.169
Gender	.10	1.23	.220
Chronic Stress	**.46**	**5.65**	**<.001**

Note. *N = 133;* Significant predictors are presented in bold: *p ≤ .05, **p ≤ .010, ***p < .001; R2 = .28; F(8,124)= 6.08, p<.001; Gender was coded 1 (male) and 2 (female); SSRT = Stop Signal Reaction Time (ms); OSpan = Operation Span.

Supplementary Table S9. Results from the Multiple Regression Model with Worry as an Outcome

	Standardized Beta Coefficients	***t***	**p-value**
Inhibition (SSRT)	.001	.01	.993
Flexibility (Switch Costs)	.002	.04	.972
Flexibility (Verbal Fluency)	-.05	-.75	.452
Updating (Proportion Correct of Letters Recalled)	-.02	-.21	.837
Working Memory (OSpan Score)	-.04	-.58	.564
Planning (Total Score)	**-.14**	**-2.13**	**.035**
Gender	**.24**	**3.58**	**<.001**
Chronic Stress	**.56**	**8.29**	**<.001**

Note. *N* = 133; Significant predictors are presented in bold: *p ≤ .05, **p ≤ .010, ***p < .001; R2 = .51; F(8,124)= 15.83, p<.001; Gender was coded 1 (male) and 2 (female); SSRT = Stop Signal Reaction Time (ms); OSpan = Operation Span.

Appendix D:
Supplementary Materials from Chapter 4

D.1 Descriptives

Table S1. Means and Standard Deviations across each MAST Stage and for each Stress Outcome

	MAST Stage							
	Baseline		Instructions		Stressor		Resting	
Stress Outcome	Exp M (SD)	Ctl M (SD)	Exp M (SD)	Ctl M (SD)	Exp M (SD)	Ctl M (SD)	Exp M (SD)	Ctl M (SD)
SBP	108.37	105.05	110.59	104.18	117.04	102.61	108.16	103.59
	(11.91)	(11.88)	(13.03)	(11.53)	(15.10)	(10.60)	(11.62)	(11.18)
DBP	73.67	73.55	74.86	73.50	80.15	72.64	74.24	73.73
	(7.81)	(6.02)	(7.37)	(6.20)	(10.65)	(5.57)	(7.73)	(7.67)
	72.75	73.55	73.73	73.50	76.82	72.64	72.30	73.73
	(8.37)	(6.02)	(7.26)	(6.20)	(8.70)	(5.57)	(8.29)	(7.67)
HR	69.65	70.69	73.93	73.54	76.76	72.20	67.27	70.79
	(9.92)	(11.48)	(9.54)	(11.32)	(9.72)	(10.82)	(9.20)	(10.75)
RMSSD	49.13	46.09	44.57	46.07	43.47	48.21	53.33	46.76
	(25.79)	(25.11)	(21.32)	(25.30)	(18.67)	(23.06)	(23.82)	(22.24)
SCL	9.65	10.16	12.22	12.01	12.50	10.75	10.80	10.53
	(3.20)	(3.59)	(3.80)	(4.30)	(3.40)	(3.81)	(3.36)	(4.37)
Stress	1.89	1.59	3.01	1.61	3.51	1.30	1.50	1.02
	(1.67)	(1.59)	(1.91)	(1.69)	(2.07)	(1.37)	(1.48)	(1.52)
STAI	28.90	27.43	-	-	41.63	27.59	29.81	27.25
	(5.34)	(6.55)			(10.79)	(6.01)	(6.69)	(7.16)

CTL = Control Group; *DBP* = Diastolic Blood Pressure; *EXP* = Experimental Group; *HR* = Heart Rate; *RMSSD* = Root Mean Square of Successive Differences Between Normal Heartbeats; *SBP* = Systolic Blood Pressure; *SCL* = Skin Conductance Levels; *STAI* = State-Trait Anxiety Inventory. Please note that for interpretation purposes, the values presented here are not transformed.

D.2 Stress Induction Verifications – Supplementary Information

Due to violations of variance homogeneity, systolic blood pressure data were log-transformed. Significant outliers as well as issues with both normality and homogeneity of variance were observed for the diastolic blood pressure values. Log-transformations and selecting a subsample of participants in the experimental group did not solve the issue; thus, a robust-ANOVA was performed using the WRS2 package. Normality assumptions were violated for RMSSD, necessitating log transformation of the outcome. The assumption for homogeneity of variance was not respected for the mean skin conductance levels models. The outcome was log-transformed. Normality assumptions were not met for the stress items. despite attempts to address this through log-transformations and sub-sample analysis. Consequently, a robust ANOVA was conducted. Homogeneity of variance and normality assumptions were not respected for the STAI. Transforming the outcome and sub-sample analysis did not solve the problem. Hence, we conducted robust-method ANOVA. For all models, the ANOVAs and post-hoc results are identical for the original sample despite the assumptions not being met, therefore we report the original ANOVAs.

Systolic Blood Pressure

A repeated-measures ANOVA was performed to evaluate the effect of time and group on systolic blood pressure. The means and standard deviations for systolic blood pressure are presented in Table S1. Mauchly's test indicated that the assumption of sphericity had been violated, $\chi2(5) = 49.25$, p <.001, and therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.81$). The effects of time [particularly its quadratic effect $F(1,136)= 28.44$, p = <.001, *partial* $\eta2 = .17$] and group [$F(1,136)= 11.13$; $p = .001$, *partial* $\eta2 = .08$] were significant. Significant differences in mean systolic blood pressure were observed for all phases in the experimental group, except between baseline and resting phases. There were no significant changes in systolic blood pressure across the control group.

Diastolic Blood Pressure

A repeated-measures ANOVA was performed to evaluate the effect of time and group on diastolic blood pressure. The means and standard deviations for diastolic blood pressure are presented in Table S1. Mauchly's test indicated that the assumption of sphericity had been violated, $\chi2(5) = 66.61$, p <.001, and therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.80$). The effect of time was significant, particularly its quadratic effect $F(1,136)= 14.35$, p = <.001, *partial* $\eta2 = .10$. Within the experimental group, there were significant differences in diastolic blood pressure across all phases, except for the resting phase with baseline and instructions. There were no significant changes in diastolic blood pressure across the control group. The main effect of group was not significant [$F(1,136)= 3.66$, $p = .058$, *partial* $\eta2 = .03$].

Heart Rate

A repeated-measures ANOVA was performed to evaluate the effect of time and group on heart rate. The means and standard deviations for heart rate are presented in Table S1. Mauchly's test indicated that the assumption of sphericity had been violated, $\chi2(5) = 66.61$, p <.001, and therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.80$). The main effects of time was significant, particularly the quadratic effect [$F(1,132)= 53.92$, p <.001, *partial* $\eta2 = .29$], while the main effect of group was not [$F(1,132)= 0.003$, $p = .957$, *partial* $\eta2 = .000$]. There were significant differences in heart rate across all phases for the experimental group. In the control group, significant differences emerged between baseline and instructions, and between instructions and resting phase.

RMSSD

A repeated-measures ANOVA was performed to evaluate the effect of time and group on RMSSD. The means and standard deviations for RMSSD are presented in Table S1. Mauchly's test indicated that the assumption of sphericity had been violated, $\chi 2(5) = 20.50$, $p < .001$, and therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.92$). The effect of time was significant, particularly its quadratic effect $F(1,133) = 12.92$, $p = < .001$, *partial* $\eta 2 = .09$. The main effect of group was not significant [$F(1,133) = 0.05$, $p = .832$, *partial* $\eta 2 = .000$]. For the experimental group, significant differences were evident across all phases, with the exception of the instruction and reactivity phases. No significant differences were observed for the control group.

Skin Conductance Levels

A repeated-measures ANOVA was performed to evaluate the effect of time and group on skin conductance levels. The means and standard deviations for skin conductance levels are presented in Table S1. Mauchly's test indicated that the assumption of sphericity had been violated, $\chi 2(5) = 66.61$, $p < .001$, and therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.80$). The main effects of time [particularly the quadratic effect, $F(1,134) = 180.98$, $p < .001$, *partial* $\eta 2 = .58$] was significant, while the main effect of group was not [$F(1,134) = 0.48$, $p = .491$, *partial* $\eta 2 = .004$]. Average skin conductance was significantly different across all MAST phases within the experimental group, with the exception of instructions and stressor phase. A time effect for the control group was also observed, with significant differences between baseline and instructions ($p < .001$), instructions and stressor ($p < .001$), and instructions and resting ($p = .001$) phases.

Self-reported Stress

A repeated-measures ANOVA was performed to evaluate the effect of time and group on self-reported stress. The means and standard deviations are presented in Table S1. Mauchly's test indicated that the assumption of sphericity had been violated, $\chi 2(5) = 20.99$, $p < .001$, and therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.92$). The main effects of time [particularly the quadratic effect, $F(1,136) = 85.96$, $p < .001$, *partial* $\eta 2 = .39$] and group [$F(1,136) = 15.29$, $p < .001$, *partial* $\eta 2 = .101$] were significant. The experimental group exhibited significant differences in stress across all phases. The control group showed significant differences between baseline and resting levels ($p = .007$) and between instructions and resting levels ($p = .041$).

Self-reported Anxiety

A repeated-measures ANOVA was performed to evaluate the effect of time and group on self-reported anxiety. The means and standard deviations for self-reported anxiety are presented in Table S1. Mauchly's test indicated that the assumption of sphericity had been violated, $\chi2(2) = 37.42$, $p <.001$, and therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.80$). The main effects of time [particularly the quadratic effect, $F(1,136)= 92.95$, $p < .001$, *partial* $\eta2 = .41$] and group [$F(1,136)= 26.09$, $p < .001$, *partial* $\eta2 = .16$]. were significant. There were significant differences between stressor and both baseline (p <.001) and resting (p <.001) phases in the experimental group. There were no significant differences in anxiety scores for the control group.

D.3 Correlations between Executive Functioning and Appraisals

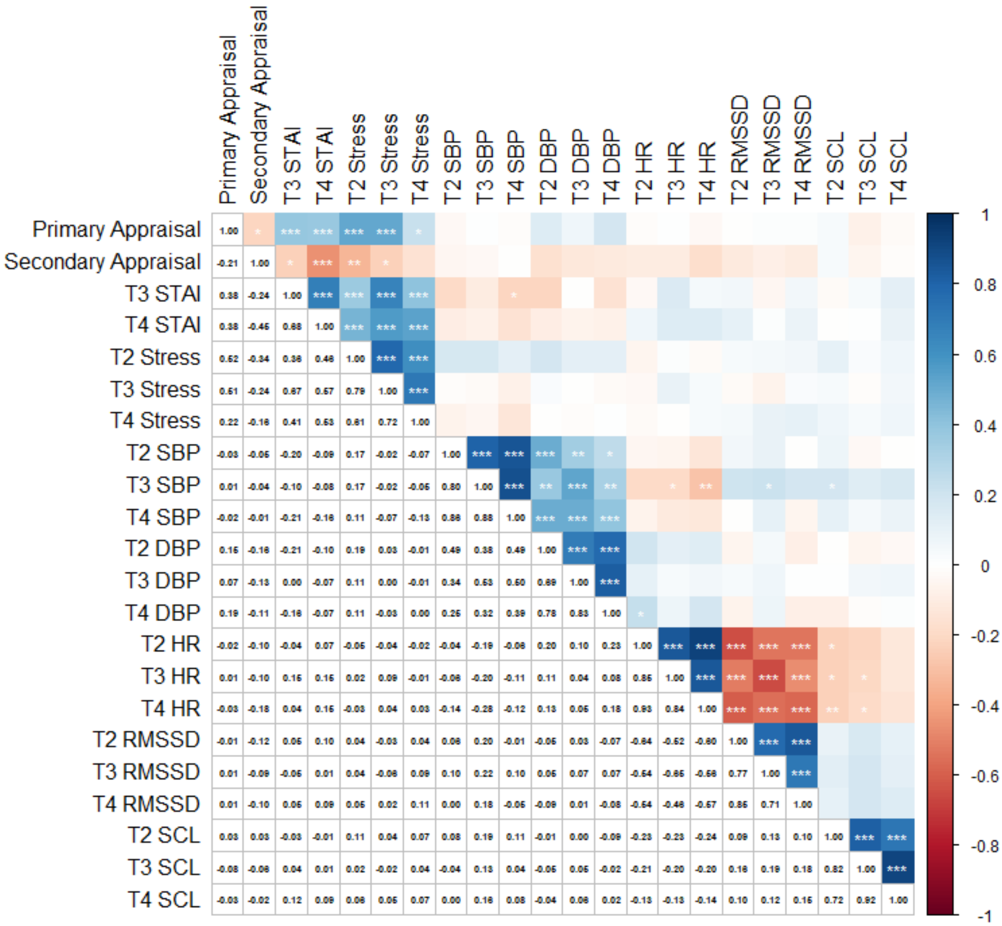
In addition to the correlations reported in the main manuscript, there were also significant associations between poorer flexibility and higher secondary appraisals (i.e., higher perceived control and self-esteem; $r(83)= -0.23$, $p=.038$). In turn, secondary appraisals were associated with lower self-reported stress during the instructions [$r(83)= -0.31$, $p =.003$] and stressor [$r(83)= -0.24$, $p =.028$], as well as lower anxiety during the stressor [$r(83)= -0.25$, $p =.022$] and following the resting period [r(83)= -0.44, $p <.001$; see Table S2].

Table S2. Correlations with Confidence Intervals for Executive Functioning and Appraisals

Variable	1	2	3	4	5
1. Flexibility					
2. Inhibition	-.10 [-.31, .11]				
3. Updating	-.02 [-.23, .19]	.04 [-.17, .25]			
4. Working Memory	-.01 [-.23, .20]	.13 [-.09, .33]	**.42**** **[-.09, .33]**		
5. Primary Appraisal	-.03 [-.24, .18]	.16 [-.36, .05]	.07 [-.14, .28]	.04 [-.18, .25]	
6. Secondary Appraisal	**-.23*** **[-.42, -.01]**	.07 [-.14, .28]	-.12 [-.32, .10]	.02 [-.19, .24]	**-.22*** **[-.41, -.00]**

*Note. N = 85; Significant effects are in bold; Values in square brackets indicate the 95% confidence interval for each correlation. * indicates* p *< .05. ** indicates* p *< .01.*

Figure S1. Pearson Correlations Between Appraisals and Stress Outcomes



Note. * indicates *p* < .05. ** indicates *p* < .01; *DBP* = Diastolic Blood Pressure; *HR* = Heart Rate; *T2* = Instructions; *T3* = Stressor (Mental Arithmetic and Hand Immersion); *T4* = Resting; *RMSSD* = Root Mean Square of Successive Differences between Normal Heartbeats; *SBP* = Systolic Blood Pressure; *SCL* = Skin Conductance Levels; *STAI* = State Trait Anxiety Questionnaire.

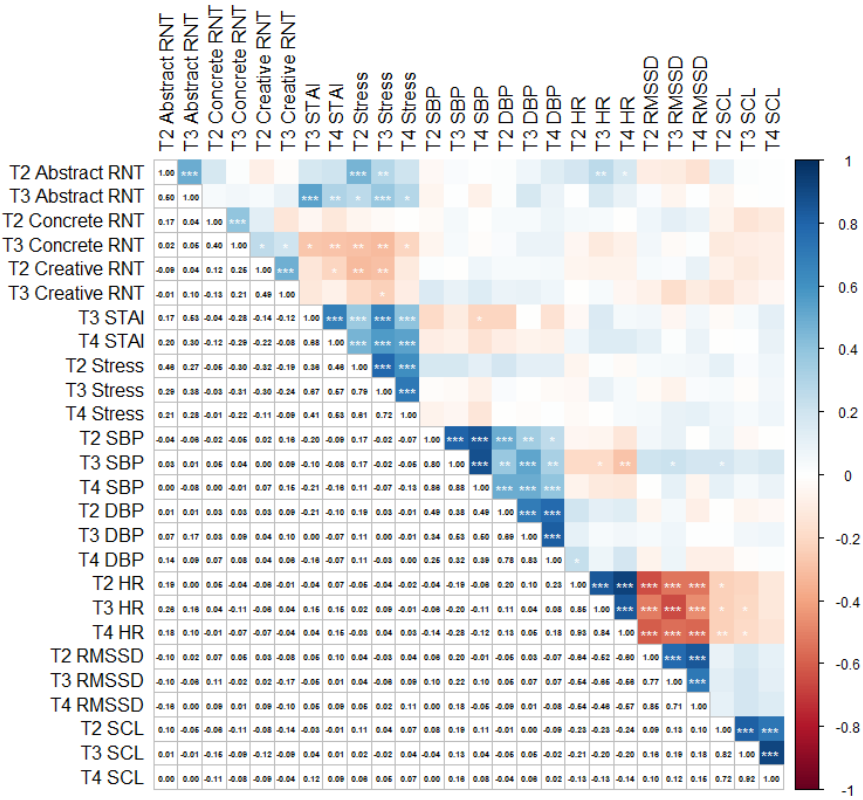
D.4 Correlations between Executive Functioning and Repetitive Negative Thinking

Table S3. Correlations with Confidence Intervals for Executive Functioning and Repetitive Negative Thinking

Variable	1	2	3	4	5	6	7	8	9
1. Flexibility									
2. Inhibition	-.10 [-.31, .11]								
3. Updating	-.02 [-.23, .19]	.04 [-.17, .25]							
4. Working Memory	-.01 [-.23, .20]	.13 [-.09, .33]	**.42**** **[.22, .58]**						
5. Anticipatory Abstract Thinking	.11 [-.11, .32]	-.13 [-.34, .08]	-.04 [-.25, .18]	.07 [-.15, .28]					
6. Stressor Abstract Thinking	.03 [-.19, .24]	.01 [-.20, .22]	-.01 [-.22, .21]	.11 [-.10, .32]	**.51**** **[.34, .66]**				
7. Anticipatory Concrete Thinking	-.14 [-.34, .07]	.00 [-.21, .22]	-.06 [-.27, .16]	-.06 [-.27, .16]	.17 [-.04, .37]	.04 [-.17, .25]			
8. Stressor Concrete Thinking	-.12 [-.32, .10]	.15 [-.06, .35]	.02 [-.20, .23]	.15 [-.07, .35]	.05 [-.16, .26]	.08 [-.13, .29]	**.39**** **[.20, .56]**		
9. Anticipatory Creative Thinking	-.11 [-.32, .10]	.10 [-.12, .30]	**-.22*** **[-.41, -.01]**	-.04 [-.25, .18]	-.09 [-.30, .13]	.02 [-.19, .23]	.12 [-.10, .32]	**.24*** **[.03, .43]**	
10. Stressor Creative Thinking	**-.34**** **[-.52, -.14]**	.15 [-.06, .36]	-.16 [-.36, .05]	.05 [-.16, .26]	-.00 [-.22, .21]	.11 [-.11, .31]	-.13 [-.33, .09]	**.21*** **[.00, .41]**	**.48**** **[.29, .63]**

Note. $N = 85$; Significant effects are in bold; Values in square brackets indicate the 95% confidence intervals for each correlation.
* indicates $p < .05$. ** indicates $p < .01$.

Figure S2. Pearson Correlations Between Repetitive Negative Thinking and Stress Outcomes



Note. * indicates *p* < .05. ** indicates *p* < .01; *DBP* = Diastolic Blood Pressure; *HR* = Heart Rate; *T2* = Instructions; *T3* = Stressor (Mental Arithmetic and Hand Immersion); *T4* = Resting; *RMSSD* = Root Mean Square of Successive Differences between Normal Heartbeats; *RNT* = Repetitive Negative Thinking; *SBP* = Systolic Blood Pressure; *SCL* = Skin Conductance Levels; *STAI* = State Trait Anxiety Questionnaire.

D.5 Mediation Models

- **Model 1:** Updating → Anticipatory creative thinking → Anticipatory stress, controlling for inhibition, flexibility, working memory capacity, baseline stress, and chronic stress
- **Model 2:** Updating → Anticipatory creative thinking → Stress reactivity, controlling for inhibition, flexibility, working memory capacity, baseline stress, and chronic stress
- **Model 3:** Updating → Anticipatory creative thinking → Anxiety recovery, controlling for inhibition, flexibility, working memory capacity, anxiety during the stressor, gender, and chronic stress
- **Model 4:** Flexibility → Creative thinking during the stressor→ Stress reactivity, controlling for inhibition, updating, working memory capacity, baseline stress, and chronic stress

Table S4. Total, Direct, and Indirect Effects for each Mediation Model

Model	Path a'	Path b'	Total effect c	Direct effect c'	Indirect effect a×b
1	**β = .26** **p = .030**	β = -.11, p = .188	β = .14, p = .087	β = .12, p = .175	β = .03, 95% CI -.01 to .10
2	**β = .26** **p = .030**	β = -.07, p = .400	**β = .21,** **p = .019**	**β = .19,** **p =.038**	β = .02, 95% CI -.02 to .07
3	β = -.23 p = .056	β = -.08, p = .342	β = .11, p = .228	β = .09, p =.330	β = .02, 95% CI -.02 to .08
4	**β = -.34** **p = .001**	β = -.13, p = .139	β = .10, p = .226	β = .06, p =.534	β = .05, 95% CI -.007 to .12

Note. N = 85; Significant effects are in bold.

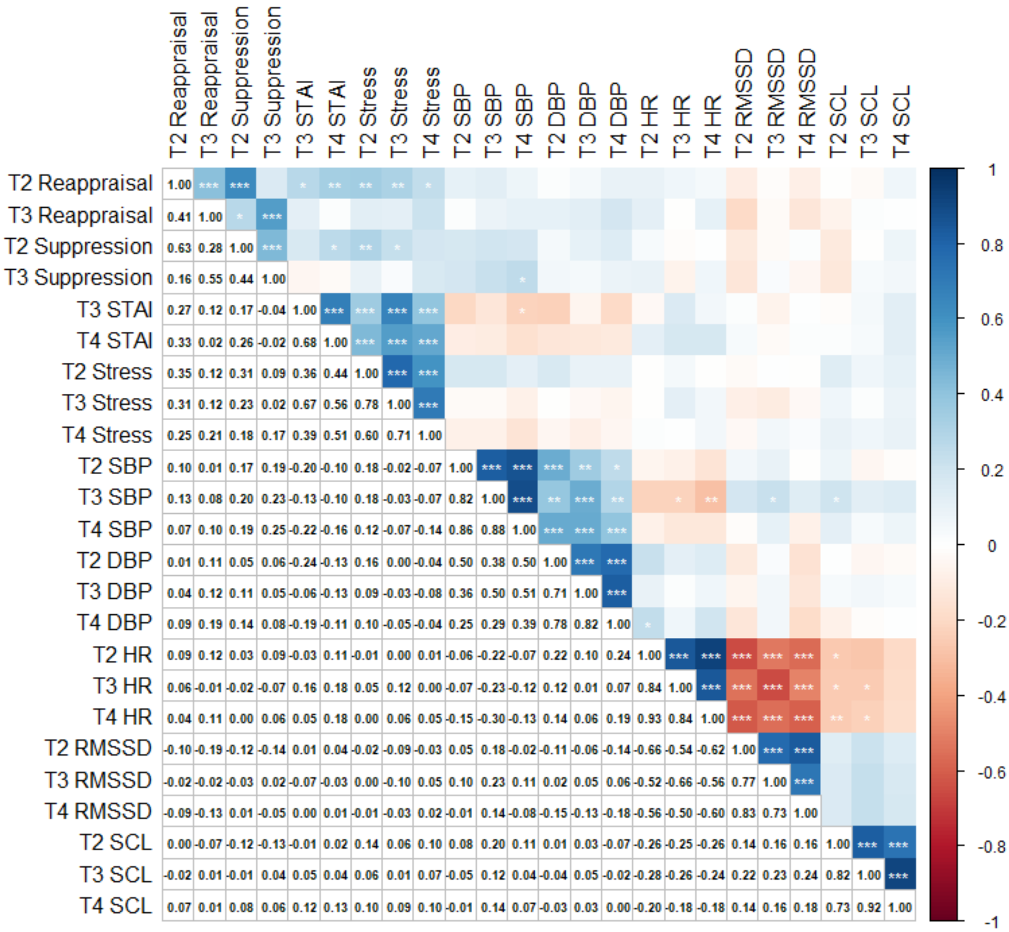
D.6 Correlations between Executive Functioning and Emotion Regulation

Table S5. Correlations with Confidence Intervals for Executive Functioning and Emotion Regulation

Variable	1	2	3	4	5	6	7
1. Flexibility							
2. Inhibition	-.10 [-.31, .11]						
3. Updating	-.02 [-.23, .19]	.04 [-.17, .25]					
4. Working Memory Capacity	-.01 [-.23, .20]	.13 [-.09, .33]	**.42** [.22, .58]**				
5. Anticipatory Reappraisal	.15 [-.07, .35]	-.10 [-.31, .12]	.10 [-.12, .31]	.13 [-.09, .33]			
6. Stressor Reappraisal	-.02 [-.23, .20]	-.07 [-.28, .15]	.06 [-.16, .28]	.20 [-.02, .40]	**.44** [.24, .60]**		
7. Anticipatory Suppression	.05 [-.17, .27]	.07 [-.29, .15]	.05 [-.17, .26]	.05 [-.17, .26]	**.62** [.46, .74]**	**.27* [.06, .46]**	
8. Stressor Suppression	.08 [-.14, .29]	.12 [-.33, .10]	.04 [-.18, .25]	.12 [-.10, .33]	.16 [-.06, .36]	**.54** [.36, .68]**	**.44** [.24, .60]**

Note. N = 85; Significant effects are in bold; Values in square brackets indicate the 95% confidence intervals for each correlation. * indicates $p < .05$. ** indicates $p < .01$.

Figure S3. Pearson Correlations Between Emotion Regulation and Stress Outcomes



Note. * indicates *p* < .05. ** indicates *p* < .01; *DBP* = Diastolic Blood Pressure; *HR* = Heart Rate; *T2* = Instructions; *T3* = Stressor (Mental Arithmetic and Hand Immersion); *T4* = Resting; *RMSSD* = Root Mean Square of Successive Differences between Normal Heartbeats; *SBP* = Systolic Blood Pressure; *SCL* = Skin Conductance Levels; *STAI* = State Trait Anxiety Questionnaire.

Appendix E:
Supplementary Materials from Chapter 5

Table S1. French and English Translations for the Ecological Momentary Assessment Items

	French item	English translation
Item Instructions	Concernant l'événement négatif reporté plus haut, dans quelle mesure, depuis la dernière notification…	Concerning the negative event reported above, to what extent, since the last notification…
Acceptance	ai-je accepté et laissé se produire l'événement	have I accepted and allowed the event to occur
Action-taking	ai-je essayé de changer la situation	have I tried to change the situation since the last notification
Avoidance	ai-je essayé de détourner mon attention des émotions associées à l'événement	have I tried to divert my attention from the emotions associated with the event
Emotion Suppression	ai-je essayé de supprimer l'expression de mes émotions	have I tried to suppress the expression of my emotions
Reappraisal	ai-je essayé de regarder la situation sous un autre angle	have I tried to look at the situation from another angle
Reflection	y ai-je pensé de manière calme et détendue	have I thought about it in a calm and relaxed way
Rumination	ai-je continué à penser à l'événement	have I continued to think about the event
Social Sharing of Emotions	ai-je parlé de mes émotions concernant l'événement à d'autres personnes	have I talked about my emotions regarding the event to other people
Solution-seeking	ai-je cherché une solution à l'événement	have I sought a solution to the event
Thought Suppression	ai-je essayé de ne plus y penser	have I tried to stop thinking about it since the last notification

Table S2. Descriptives for Individuals with and without Missing Data for all Baseline Variables

Variable	Individuals with complete data *N* = 97	Individuals with missing data *N* = 21	Group Differences
Sociodemographic Variables			
Age *M(SD)*	22.42 (3.77)	22.33 (3.64)	$F(1,116) = 0.01$, $p = .921$
Gender, *N(%)*			χ2(1, 118) = 1.17, $p = .280$
Women	64 (97.98)	17 (80.95)	
Men	33 (34.02)	4 (19.05)	
Years of Education, *M(SD)*	15.73 (2.66)	15.57 (2.18)	$F(1,116) = 0.07$, $p = .797$
Handedness, *N(%)*			χ2(2, 118) = 6.42, $p = .040$
Right-handed	91 (93.81)	17 (80.95)	
Left-handed	6 (6.19)	3 (14.29)	
Ambidexter	0 (0.00)	1 (4.76)	
Chronic Stress, *M(SD)*	14.90 (6.04)	15.52 (5.27)	$F(1,116) = 0.19$, $p = .661$
Executive Functioning			
Flexibility *M(SD)*	660.8 (437.19)	613.68 (309.79)	$F(1,115) = 0.21$, $p = .647$
Inhibition *M(SD)*	201.17 (44.11)	185.95 (50.90)	$F(1,111) = 1.57$, $p = .214$
Updating *M(SD)*	0.88 (0.13)	0.91 (0.10)	$F(1,115) = 1.32$, $p = .253$
WMC *M(SD)*	43.07 (17.88)	44.25 (19.88)	$F(1,111) = 0.06$, $p = .810$

Notes. WMC = Working Memory Capacity.

Table S3. Pearson and Spearman Correlations between Executive Functioning, Working Memory Capacity, and Affect Regulation Strategies (N = 88)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Flexibility[1]	--	-.13	-.16	-.03	.03	.07	-.17	.02	-.16	.00	**.25***	-.01	-.09	-.04
2. Inhibition[1]	-.20	--	.05	.06	-.08	-.05	.18	-.16	.12	-.11	-.13	.05	-.01	-.11
3. Updating[1]	-.16	.07	--	**.38*****	.20	**.28****	.15	.08	.13	.00	-.14	.01	-.08	.06
4. WMC	.02	.14	**.38*****	--	.16	**.21***	-.03	.02	.20	-.07	-.06	.00	.00	.01
5. Action	.15	-.07	.15	.12	--	**.68*****	-.17	.20	-.13	.07	.20	.07	-.14	.18
6. Solution	.15	-.03	**.25***	**.21***	.67***	--	-.19	.34**	.13	.17	.17	.04	-.08	.04
7. Acceptance	**-.25***	.18	.15	-.03	-.17	-.18	--	.18	-.05	.10	**-.40*****	.14	.11	.17
8. Reappraisal	.08	-.14	.09	.03	**.22***	**.32****	.17	--	.06	**.37*****	-.05	**.30****	**.24***	**.24***
9. Reflection	**-.25***	.10	.18	**.23***	-.11	.13	-.005	.03	--	.01	**-.24***	.17	.01	-.01
10. Social Emotions	.01	-.07	-.05	-.05	.08	.15	.10	**.36****	-.002	--	-.02	.18	**.22***	.10
11. Rumination	**.26***	-.10	-.16	-.10	.19	.13	**-.41*****	-.06	**-.29****	-.03	--	-.18	-.17	-.02
12. Avoidance	-.010	.11	.03	.004	.09	.04	.10	**.31****	.12	.18	-.19	--	**.55*****	**.31****
13. Thought Suppression	-.05	.02	-.06	.01	-.10	-.08	.13	**.25***	-.04	**.22***	-.12	**.58*****	**--**	**.31****
14. Emotion Suppression	-.04	-.08	.006	.02	.16	.03	.13	.21	-.01	.09	-.03	**.30****	**.31****	--

Note. [1] indicates non-normally distributed variables. The Pearson correlations are available above the diagonal, while the Spearman correlations are shown below it. The correlations significance changed when removing outliers, thus we report the results for those without them (N = 88). Observed ranges were from 1-7 except for Rumination that ranged from 2.25 to 7 and Avoidance that ranged from 1 to 6.60. *WMC* = Working Memory Capacity

Table S4. Pearson Correlations between Executive Functioning, Working Memory Capacity, and Primary and Secondary Cognitive Appraisals

	Pearson Correlations		Spearman Correlations	
	Primary Appraisal	Secondary Appraisal	Primary Appraisal	Secondary Appraisal
Flexibility[1]	.02	.08	-.03	.07
Inhibition[1]	.02	-.12	-.03	-.14
Updating[1]	-.01	.07	-.02	.10
WMC	-.04	.07	-.04	.12
Proximal Reactivity[1]	-.08	**-.15***	-.09	-.11
Cumulative Reactivity[1]	-.08	**-.21***	-.09	-.16
Proximal Recovery	-.004	**-.16****	-.03	**-.14****
Cumulative Recovery	-.07	-.10	-.13	-.08

Note. Significant correlations are presented in bold. 1 indicates non-normal distribution; * indicates p <. 05, ** p <.01, *** p <.001. WMC = Working Memory Capacity. The correlations between inhibition and appraisals do not change according to the method used nor when removing outliers, thus we report the findings for the complete sample for executive functioning and appraisals (N = 97). The correlations between appraisals and stress indices were run using multilevel correlations and significance changed when removing outliers, thus we report the results for those without them (N = 88).

Table S5. Linear Mixed Models for Stress Affect as Outcome, with Executive Functioning Facets and Working Memory Capacity as Predictors

	Stress Affect			Stress Affect			Stress Affect		
Predictors	*Std. Beta*	*Std. CI*	*p*	*Std. Beta*	*Std. CI*	*p*	*Std. Beta*	*Std. CI*	*p*
(Intercept)	**-0.01**	**-0.22 – 0.20**	**<0.001**	**-0.12**	**-0.33 – 0.09**	**<0.001**	**-0.12**	**-0.33 – 0.09**	**<0.001**
Flexibility	-0.00	-0.13 – 0.12	0.949	0.00	-0.12 – 0.13	0.980	0.01	-0.12 – 0.13	0.935
Inhibition	-0.00	-0.12 – 0.12	0.998	-0.01	-0.13 – 0.11	0.888	-0.00	-0.12 – 0.12	0.971
Updating	-0.05	-0.17 – 0.07	0.402	-0.04	-0.16 – 0.07	0.462	-0.04	-0.16 – 0.07	0.485
WMC	0.07	-0.06 – 0.20	0.283	0.07	-0.06 – 0.20	0.295	0.09	-0.05 – 0.22	0.201
Gender	0.01	-0.26 – 0.27	0.966	-0.02	-0.28 – 0.24	0.889	-0.02	-0.28 – 0.25	0.908
Chronic Stress	**0.38**	**0.26 – 0.51**	**<0.001**	**0.36**	**0.23 – 0.48**	**<0.001**	**0.36**	**0.23 – 0.48**	**<0.001**
Stressful Event				**1.08**	**1.01 – 1.15**	**<0.001**	**1.07**	**1.00 – 1.14**	**<0.001**
Flexibility × Stressor							-0.03	-0.11 – 0.05	0.515
Inhibition × Stressor							-0.07	-0.15 – 0.01	0.075
Updating × Stressor							-0.01	-0.09 – 0.07	0.787
Working Memory Capacity × Stressor							**-2.91**	**-0.20 – -0.05**	**0.001**
Random Effects									
σ^2	278.21			221.73			220.84		
τ_{00}	176.66 participant_id			178.45 participant_id			178.21 participant_id		
ICC	0.39			0.45			0.45		
N	97 participant_id			97 participant_id			97 participant_id		
Observations	3615			3615			3615		
Marginal R^2 / Conditional R^2	0.147 / 0.478			0.254 / 0.586			0.255 / 0.588		
AIC	30907.97			30109.40			30093.03		

Note. Significant predictors in bold. *WMC* = Working Memory Capacity; *AIC* = Akaike Information Criterion; *CI* = Confidence Intervals; ICC = Intraclass Correlation Coefficient; *LM* = Letter Memory (Updating); *NL* = Number-Letter Task (Flexibility); *OS* = Operation Span; *SSRT* = Stop Signal Reaction Time (Inhibition); *Std* = Standardized.

Table S6. Linear Mixed Models for Proximal and Cumulative Reactivity and Recovery, with Executive Functioning Facets and Working Memory Capacity as Predictors.

	Proximal Reactivity			Distal Reactivity			Proximal Recovery			Distal Recovery		
Predictors	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*	*Estimates*	*CI*	*p*
(Intercept)	**28.83**	**22.89 – 34.78**	**<0.001**	**30.54**	**24.42 – 36.66**	**<0.001**	**-21.24**	**-27.07 – -15.41**	**<0.001**	**-7.19**	**-13.15 – -1.22**	**0.019**
Flexibility	-0.87	-4.53 – 2.79	0.641	-0.62	-4.62 – 3.38	0.761	1.82	-1.82 – 5.46	0.325	-0.53	-4.48 – 3.42	0.790
Inhibition	-3.30	-6.73 – 0.14	0.060	-0.74	-4.49 – 3.01	0.696	0.56	-2.87 – 3.98	0.750	-0.51	-4.22 – 3.20	0.787
Updating	0.56	-3.15 – 4.28	0.766	0.36	-3.87 – 4.59	0.867	0.46	-3.11 – 4.04	0.799	-0.74	-4.94 – 3.46	0.730
Working Memory Capacity	-1.99	-5.61 – 1.63	0.280	-0.48	-4.72 – 3.76	0.824	3.06	-0.40 – 6.51	0.083	-2.07	-6.28 – 2.14	0.334
Gender	-1.37	-8.76 – 6.02	0.716	-2.68	-10.58 – 5.21	0.503	1.82	-5.36 – 9.01	0.618	0.72	-7.04 – 8.48	0.855
Chronic Stress	2.77	-0.75 – 6.29	0.123	2.03	-1.68 – 5.74	0.281	-1.22	-4.65 – 2.21	0.485	-0.14	-3.84 – 3.56	0.940
Random Effects												
σ^2	321.85			288.03			437.11			398.25		
τ_{00}	129.18 participant_id			114.75 participant_id			105.36 participant_id			69.28 participant_id		
ICC	0.29			0.28			0.19			0.15		
N	91 participant_id			88 participant_id			95 participant_id			92 participant_id		
Observations	317			164			381			174		
Marginal R^2 / Conditional R^2	0.052 / 0.323			0.015 / 0.295			0.028 / 0.217			0.015 / 0.161		

Note. Significant predictors in bold. *ICC* = Intraclass Correlation Coefficient. Sensitivity analyses were conducted with regression analyses using all variables pooled at the person-level and none of the results changed.

Figure S1a. Linear Mixed Model Assumptions for Proximal Reactivity as Outcome

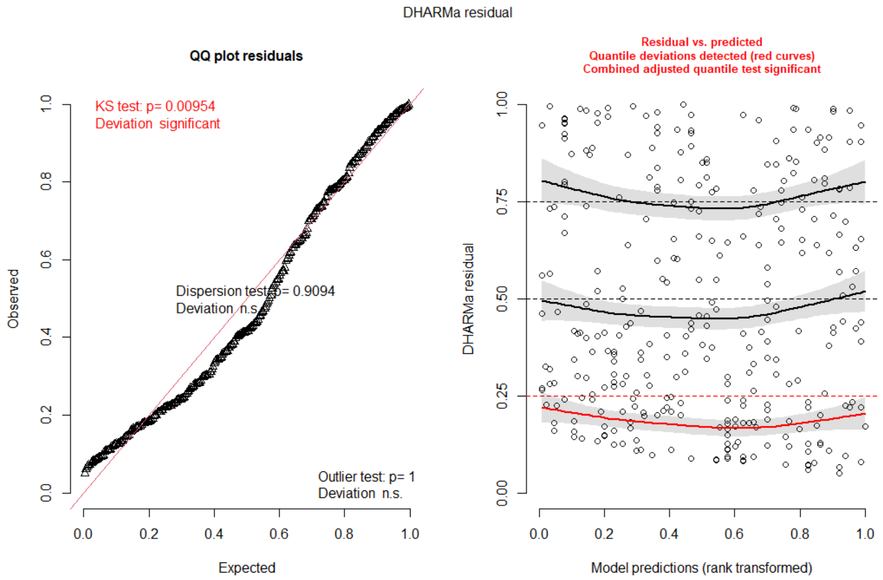


Figure S1b. Linear Mixed Model Assumptions for Log-transformed Proximal Reactivity as Outcome

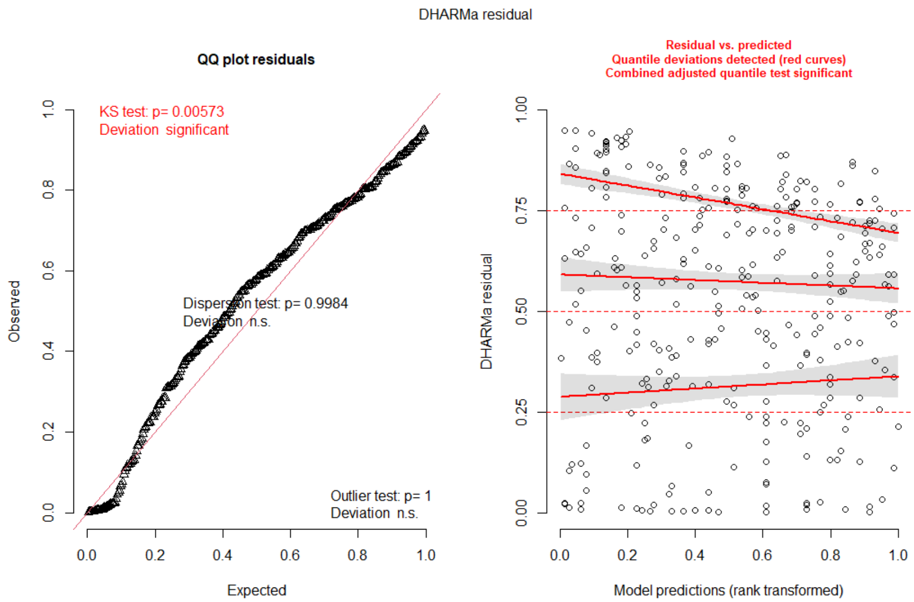


Table S7. Regression Parameters for all Multilevel Mediation Models

Term	Label	Estimate	Beta	se	z	p
1. Flexibility → Rumination → Proximal Reactivity						
Proximal Reactivity ~ Rumination	b	11.22	0.519	9.616	1.167	0.243
Proximal Reactivity ~ Flexibility	c	-0.009	-0.343	0.008	-1.150	0.250
Rumination ~ Flexibility	**a**	**0.001**	**0.574**	**0.000**	**2.826**	**0.005**
ab := a*b	ab	0.008	0.298	0.007	1.103	0.270
total := ab+c	total	-0.001	-0.044	0.004	-0.304	0.761
2. Flexibility → Reflection → Proximal Reactivity						
Proximal Reactivity ~ Reflection	b	-0.88	-0.08	2.38	-0.37	0.712
Proximal Reactivity ~ Flexibility	c	-0.002	-0.07	0.004	-0.42	0.672
Reflection ~ Flexibility	a	-0.001	-0.28	0.000	-1.95	0.051
ab := a*b	ab	0.001	0.02	0.001	0.37	0.713
total := ab+c	total	-0.001	-0.05	0.004	-0.31	0.757
3. Flexibility → Reflection → Cumulative Reactivity						
Distal Reactivity ~ Reflection	b	-2.94	-0.32	2.83	-1.04	0.299
Distal Reactivity ~ Flexibility	c	-0.003	-0.12	0.004	-0.64	0.525
Reflection ~ Flexibility	a	-0.001	-0.23	0.000	-1.50	0.134
ab := a*b	ab	0.002	0.07	0.002	0.89	0.376
total := ab+c	total	-0.001	-0.04	0.004	-0.25	0.804
4. Flexibility → Reflection → Proximal Recovery						
Proximal Recovery ~ Reflection	**b**	**4.88**	**0.46**	**2.16**	**2.26**	**0.024**
Proximal Recovery ~ Flexibility	c	0.005	0.22	0.004	1.35	0.176
Reflection ~ Flexibility	a	-0.001	-0.25	0.000	-1.76	0.078
ab := a*b	ab	-0.003	-0.11	0.002	-1.41	0.159
total := ab+c	total	0.002	0.11	0.004	0.66	0.507

Table S8. Pearson Correlations between Executive Functioning. Working Memory Capacity, and Variability in Affect Regulation Strategies (N =97)

		1	2	3	4	5	6	7	8	9	10	11	12	13
1.	Inhibition[1]	1	-.10	.01	.03	-.01	.06	.03	.19	-.02	.14	-.10	-.05	-.10
2.	Flexibility[1]	-.19	1	**-.33****	-.07	.14	-.04	.06	.15	.17	.13	-.09	.06	-.03
3.	Updating[1]	.03	**-.24***	1	**.40*****	.05	.07	.07	-.09	-.15	-.07	**.26***	-.04	.16
4.	WMC	.13	-.03	**.41*****	1	.06	.01	.05	.04	.06	.08	.19	.00	.14
5.	Within-Adaptive	-.002	**.25***	.04	.03	1	**.37****	**.84*****	**.35****	**.46*****	**.48*****	-.02	-.21	-.14
6.	Within-Maladaptive	.05	.04	.08	.07	**.39*****	1	**.81*****	.19	.04	**.23***	.15	.06	.14
7.	Within-Total	.03	.19	.05	.07	**.82*****	**.82*****	1	**.33****	**.32****	**.44*****	.07	-.10	.00
8.	Between-Adaptive	.06	.11	-.09	.06	**.36****	**.25***	**.33****	1	**.44*****	**.78*****	**-.40*****	**-.21***	**-.40*****
9.	Between-Maladaptive	-.02	**.22***	-.19	.04	**.36****	.03	.20	**.43*****	1	**.75*****	**-.28****	**-.47*****	**-.46*****
10.	Between-Total	.09	.13	-.10	.07	**.46*****	**.28***	**.41*****	**.78*****	**.72*****	1	**-.30****	**-.37*****	**-.41*****
11.	Endorsement-Adaptive	-.05	.007	**.24***	.16	-.05	.16	.09	**-.37*****	**-.30****	**-.32****	1	**.24***	**.85*****
12.	Endorsement-Maladaptive	-.01	.03	-.05	.02	-.19	.09	-.01	**-.21***	**-.43*****	**-.35*****	**.20***	1	**.72*****
13.	Endorsement-Total	-.05	.02	.18	.13	-.15	.14	.02	**-.42*****	**-.46*****	**-.42*****	**.83*****	**.67*****	1

Note. [1] indicates non-normally distributed variables. Significant correlations in bold. * indicates *p* <. 05, ** *p* <.01, *** *p* <.001. *WMC* = Working Memory Capacity. The Pearson correlations are available above the diagonal, while the Spearman correlations are shown below it. The correlations change according to the method used but not when removing outliers, thus we report the findings for the complete sample (*N* = 97).

Table S9. Pearson Correlations between Executive Functioning. Working Memory Capacity, and Variability in Affect Regulation Strategies (N =97)

	Within-variability Adaptive Strategies			**Within-variability Maladaptive Strategies**			**Within-variability across all Strategies**		
Predictors	*Standardized Beta*	*Standardized CI*	*p*	*Standardized Beta*	*Standardized CI*	*p*	*Standardized Beta*	*Standardized CI*	*p*
(Intercept)	**0.13**	**-0.35 – 0.61**	**0.067**	**0.33**	**-0.15 – 0.81**	**0.012**	**0.27**	**-0.21 – 0.75**	**0.010**
Flexibility	0.15	-0.11 – 0.42	0.249	-0.01	-0.27 – 0.25	0.955	0.09	-0.17 – 0.36	0.484
Inhibition	-0.01	-0.26 – 0.24	0.952	0.01	-0.23 – 0.26	0.909	0.00	-0.25 – 0.25	0.978
Updating	0.09	-0.19 – 0.37	0.526	0.05	-0.23 – 0.33	0.720	0.09	-0.20 – 0.37	0.544
WMC	0.06	-0.20 – 0.33	0.644	-0.05	-0.31 – 0.22	0.720	0.01	-0.25 – 0.28	0.931
Chronic Stress	0.17	-0.08 – 0.42	0.184	-0.01	-0.26 – 0.24	0.942	0.10	-0.15 – 0.35	0.423
Age	-0.05	-0.32 – 0.22	0.706	-0.25	-0.52 – 0.01	0.060	-0.18	-0.45 – 0.09	0.187
Gender	-0.19	-0.77 – 0.40	0.529	-0.46	-1.05 – 0.12	0.116	-0.38	-0.97 – 0.20	0.194
Observations	73			73			73		
R^2 / R^2 adjusted	0.064 / -0.037			0.077 / -0.022			0.065 / -0.036		

Note. Significant predictors in bold. *CI* = Confidence Intervals. *WMC* = Working Memory Capacity.

Table S10. Linear Regression Models for Between-Variability Indices of Affect Regulation Variability, with Executive Functioning Facets and Working Memory Capacity as Predictors

	Between-variability Maladaptive Strategies			**Between-variability across all Strategies**		
Predictors	*Standardized Beta*	*Standardized CI*	*p*	*Standardized Beta*	*Standardized CI*	*p*
(Intercept)	**0.38**	**0.03 – 0.74**	**0.001**	**0.54**	**0.20 – 0.89**	**<0.001**
Flexibility	0.10	-0.11 – 0.31	0.338	0.09	-0.11 – 0.30	0.358
Inhibition	-0.02	-0.22 – 0.18	0.858	0.17	-0.03 – 0.36	0.094
Updating	-0.22	-0.45 – 0.01	0.063	-0.14	-0.37 – 0.08	0.201
WMC	0.10	-0.11 – 0.32	0.346	0.09	-0.12 – 0.30	0.413
Chronic Stress	-0.06	-0.26 – 0.15	0.586	0.08	-0.12 – 0.28	0.447
Age	-0.02	-0.23 – 0.19	0.833	0.02	-0.18 – 0.22	0.841
Gender	**-0.58**	**-1.03 – -0.13**	**0.012**	**-0.82**	**-1.26 – -0.39**	**<0.001**
Observations	97			97		
R^2 / R^2 adjusted	0.131 / 0.063			0.194 / 0.131		

Note. Significant predictors in bold. *CI* = Confidence Intervals. *WMC* = Working Memory Capacity.

Table S11. Linear Regression Models for Mean Endorsement Indices of Affect Regulation Variability, with Executive Functioning Facets and Working Memory Capacity as Predictors

	Mean Endorsement Adaptive Strategies			Mean Endorsement Maladaptive Strategies			Mean Endorsement across all Strategies		
Predictors	*Standardized Beta*	*Standardized CI*	*p*	*Standardized Beta*	*Standardized CI*	*p*	*Standardized Beta*	*Standardized CI*	*p*
(Intercept)	**-0.19**	**-0.54 – 0.15**	**<0.001**	**-0.41**	**-0.78 – -0.05**	**0.009**	**-0.37**	**-0.72 – -0.01**	**<0.001**
Flexibility	-0.00	-0.21 – 0.20	0.993	0.07	-0.14 – 0.29	0.514	0.04	-0.17 – 0.25	0.719
Inhibition	-0.15	-0.34 – 0.05	0.133	-0.04	-0.25 – 0.17	0.698	-0.13	-0.33 – 0.07	0.206
Updating	0.22	-0.01 – 0.44	0.059	0.03	-0.21 – 0.27	0.803	0.17	-0.06 – 0.40	0.145
WMC	0.07	-0.14 – 0.28	0.493	0.05	-0.17 – 0.28	0.642	0.08	-0.14 – 0.30	0.461
Chronic Stress	**-0.29**	**-0.49 – -0.09**	**0.005**	0.04	-0.17 – 0.25	0.714	-0.19	-0.39 – 0.02	0.079
Age	-0.12	-0.33 – 0.08	0.233	0.03	-0.19 – 0.24	0.792	-0.07	-0.28 – 0.14	0.494
Gender	0.29	-0.14 – 0.73	0.184	**0.62**	**0.16 - 1.08**	**0.008**	**0.55**	**0.10 - 1.00**	**0.017**
Observations	97			97			97		
R^2 / R^2 adjusted	0.182 / 0.118			0.092 / 0.021			0.133 / 0.064		

Note. Significant predictors in bold. *CI* = Confidence Intervals. WMC = Working Memory Capacity

Table S12. Pearson Correlations between Executive Functioning, Working Memory Capacity, Reactivity and Recovery, and Flexibility in Affect Regulation Strategies (*N* = 73)

		1	2	3	4	5	6	7	8	9	10	11
1.	Inhibition[1]	1	-.10	.08	.17	-.08	-.03	-.003	**-.28***	-.10	-.19	-.008
2.	Flexibility[1]	-.16	1	**-.28***	-.09	.005	-.17	.09	-.06	-.05	-.02	.05
3.	Updating[1]	.08	**-.28***	1	**.38*****	-.09	-.19	.003	.07	-.09	.05	-.20
4.	WMC[1]	.20	-.09	**.37****	1	-.22	-.06	.03	-.14	**-.24***	-.04	-.18
5.	Adaptive Differentiation	-.16	.07	-.12	-.21	1	.23	.20	-.13	-.06	-.30	-.005
6.	Maladaptive Differentiation	.15	-.08	-.24	-.03	-.10	1	.17	-.15	-.29	**-.34***	-.20
7.	Total Differentiation	.03	.09	.04	-.03	.07	.14	1	-.09	-.05	-.17	-.03
8.	Proximal Reactivity	**-.27***	-.02	-.01	-.22	-.13	-.17	-.04	1	**.47*****	**.82*****	**-.34*****
9.	Immediate Recovery	-.07	-.10	-.10	**-.29***	-.11	**-.33***	-.02	**.53*****	1	**.53*****	**.40*****
10.	Cumulative Reactivity	-.19	-.05	.04	-.09	-.32	-.27	-.09	**.81*****	**.54*****	1	-.20
11.	Cumulative Recovery	-.09	.06	-.15	-.19	-.06	-.16	-.04	-.19	**.41*****	-.11	1

Note. [1] indicates non-normally distributed variables. Significant correlations in bold. *WMC* = Working Memory Capacity. The Pearson correlations are available above the diagonal, while the Spearman correlations are shown below it. The results are identical regardless of the correlation method used

Appendix F:
Supplementary Materials from Chapter 6

F.1 Study 1 – Affective Flexibility and Acute Stress in the Laboratory

Further details on statistical analyses

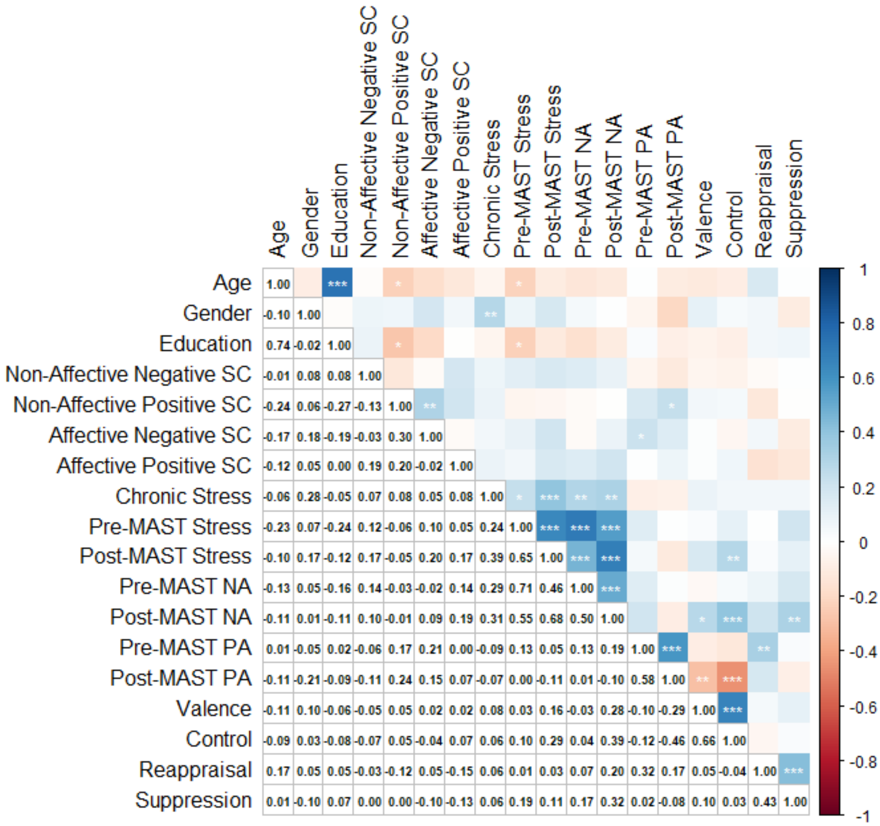
Using suppression with three and four items leads to different result. For example, affective negative switch costs become significant predictors of suppression in the regression model when considering the full four-item variable. Thus, we report the results for the latter only but acknowledge the lower power and warrant for caution while interpreting this result.

Stress Induction Verification

All model assumptions were verified, when they were not respected, we either used log-transformed outcomes or robust ANOVAs. When there was no significant difference in results, we reported the former. For example, we log-transformed the output or used robust-ANOVAs (using packages "*lmtest*" and "*sandwich*") when homogeneity of variances was not present. However, as the results were unchanged compared to the regular ANOVA, we present the latter across the three outcomes.

Correlations

Figure S1. Pearson Correlations between all Study 1 Variables



Regression Models

To meet model assumptions for correlations and regressions, the normality in the distribution of all predictor and outcome variables were verified.

Table S1 – Negative and Positive Affect. Regression Models for Affective Flexibility Predicting Post-MAST Affect

	Log-transformed Negative Affect			**Positive Affect**		
Predictors	*Std. Beta*	*Standardized CI*	*p*	*Std. Beta*	*Standardized CI*	*p*
Pre-MAST Negative / Positive Affect	0.43	0.22 – 0.63	**<0.001**	0.56	0.38 – 0.75	**<0.001**
Non-Affective Positive SC	-0.10	-0.31 – 0.11	0.345	0.11	-0.09 – 0.31	0.272
Non-Affective Negative SC	-0.04	-0.23 – 0.16	0.713	-0.07	-0.26 – 0.11	0.443
Affective Positive SC	0.14	-0.06 – 0.34	0.167	0.06	-0.13 – 0.25	0.564
Affective Negative SC	0.12	-0.08 – 0.32	0.246	-0.02	-0.22 – 0.17	0.834
Age	-0.04	-0.24 – 0.16	0.717	-0.08	-0.27 – 0.11	0.389
Chronic Stress	0.18	-0.02 – 0.38	0.074	-0.03	-0.22 – 0.15	0.705
Observations	84			84		
R^2 / R^2 adjusted	0.311 / 0.248			0.376 / 0.318		

Note. Given the absence of results when modifications were made to meet model assumptions, these are the original models; *CI* = Confidence Intervals; *SC* = Switch Cost; *Std* = Standardized.

Table S2 – Appraisal. Regression Models for Appraisals as Outcomes and Affective Flexibility as Predictor

	Valence			**Control**		
Predictors	*Std. Beta*	*Standardized CI*	*p*	*Std. Beta*	*Standardized CI*	*p*
Non-Affective Positive SC	0.02	-0.23 – 0.27	0.897	0.02	-0.23 – 0.27	0.868
Non-Affective Negative SC	-0.06	-0.29 – 0.17	0.618	-0.08	-0.32 – 0.15	0.477
Affective Positive SC	0.01	-0.23 – 0.24	0.953	0.06	-0.18 – 0.30	0.611
Affective Negative SC	-0.01	-0.25 – 0.23	0.915	-0.07	-0.30 – 0.17	0.579
Age	-0.10	-0.34 – 0.13	0.374	-0.09	-0.32 – 0.14	0.436
Chronic Stress	0.08	-0.15 – 0.30	0.496	0.06	-0.17 – 0.28	0.628
Observations	84			84		
R^2 / R^2 adjusted	0.022 / -0.054			0.025 / -0.051		

Note. Given the absence of results when modifications were made to meet model assumptions, these are the original models. *CI* = Confidence Intervals; *SC* = Switch Cost; *Std* = Standardized.

Table S3 – Affect Regulation. Regression Models for Emotion Regulation as Outcomes and Affective Flexibility as Predictor

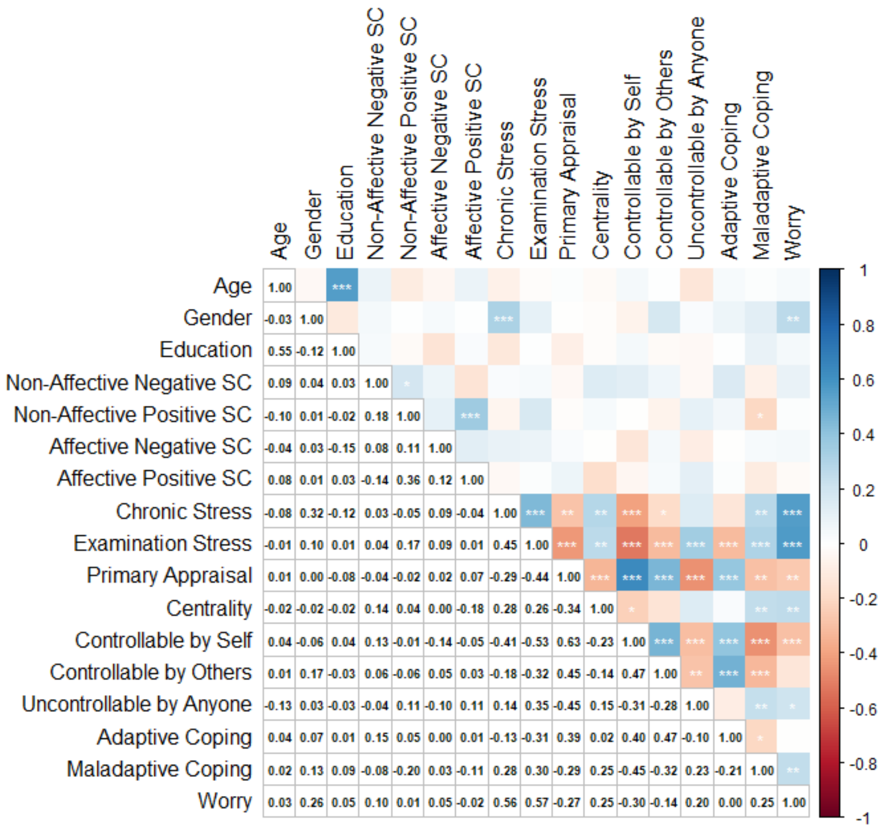
	Reappraisal			**Suppression**		
Predictors	*Std. Beta*	*Standardized CI*	*p*	*Std. Beta*	*Standardized CI*	*p*
Non-Affective Positive SC	-0.10	-0.35 – 0.14	0.394	0.06	-0.19 – 0.31	0.624
Non-Affective Negative SC	-0.02	-0.25 – 0.21	0.851	0.03	-0.20 – 0.26	0.789
Affective Positive SC	-0.12	-0.35 – 0.12	0.323	-0.16	-0.39 – 0.08	0.186
Affective Negative SC	0.11	-0.13 – 0.34	0.368	-0.13	-0.36 – 0.11	0.288
Age	0.15	-0.08 – 0.38	0.186	-0.01	-0.24 – 0.22	0.914
Chronic Stress	0.08	-0.14 – 0.30	0.474	0.07	-0.15 – 0.30	0.529
Observations	84			84		
R^2 / R^2 adjusted	0.068 / -0.005			0.037 / -0.038		

Note. CI = Confidence Intervals; *SC* = Switch Cost; *Std* = Standardized.

F.2 Study 2 – Affective Flexibility and Academic Stress

Correlations

Figure S2. Pearson Correlations between all Study 2 Variables



Data Analysis

Removing the outliers modified the results for several regression models, therefore we report those without them.

Table S4 – Centrality Appraisals. Regression Model for Centrality as an Outcome and Affective Flexibility as a Predictor

	Centrality		
Predictors	*Std. Beta*	*Standardized CI*	*p*
Non-Affective Negative SC	0.09	-0.09 – 0.27	0.307
Non-Affective Positive SC	0.11	-0.08 – 0.29	0.272
Affective Negative SC	-0.02	-0.20 – 0.15	0.797
Affective Positive SC	-0.18	-0.37 – 0.00	0.055
Gender	-0.31	-0.79 – 0.16	0.192
Chronic Stress	0.32	0.14 – 0.50	0.001
Observations	123		
R2 / R2 adjusted	0.142 / 0.097		

Note. CI = Confidence Intervals; SC = Switch Cost; Std = Standardized.

Table S5 – Control Appraisals. Regression Models for Perceptions of Control as Outcomes and Affective Flexibility as Predictor

	Controllable by oneself			Controllable by others		
Predictors	*Std. Beta*	*Standardized CI*	*p*	*Std. Beta*	*Standardized CI*	*p*
Non-Affective Negative SC	0.15	-0.02 – 0.32	0.084	0.09	-0.09 – 0.27	0.345
Non-Affective Positive SC	-0.04	-0.22 – 0.14	0.657	-0.13	-0.32 – 0.07	0.195
Affective Negative SC	-0.10	-0.27 – 0.06	0.221	0.06	-0.11 – 0.24	0.478
Affective Positive SC	-0.02	-0.20 – 0.17	0.863	0.07	-0.12 – 0.26	0.462
Gender	0.19	-0.27 – 0.65	0.414	0.67	0.18 – 1.15	0.007
Chronic Stress	-0.43	-0.60 – -0.25	<0.001	-0.27	-0.46 – -0.09	0.004
Observations	123			123		
R^2 / R^2 adjusted	0.204 / 0.163			0.112 / 0.066		

Note. The normality of residuals assumption was not respected for controllable by others. While log-transforming the results solved this problem, none of the results changed. Thus, we report the initial model. *CI* = Confidence Intervals; *SC* = Switch Cost; *Std* = Standardized.

Table S6 - Adaptive and Maladaptive Coping. Regression Models for Adaptive and Maladaptive Coping as Outcomes and Affective Flexibility as Predictor

	Maladaptive Coping			**Adaptive Coping**		
Predictors	*Std. Beta*	*Standardized CI*	*p*	*Std. Beta*	*Standardized CI*	*p*
Non-Affective Negative SC	-0.07	-0.25 – 0.11	0.446	0.16	-0.03 – 0.34	0.102
Non-Affective Positive SC	-0.16	-0.35 – 0.03	0.101	0.01	-0.19 – 0.21	0.931
Affective Negative SC	0.04	-0.14 – 0.21	0.681	-0.01	-0.19 – 0.17	0.932
Affective Positive SC	-0.06	-0.25 – 0.13	0.549	0.03	-0.17 – 0.22	0.799
Gender	0.13	-0.35 – 0.61	0.597	0.32	-0.18 – 0.82	0.212
Chronic Stress	0.25	0.07 – 0.43	**0.008**	-0.17	-0.36 – 0.02	0.079
Observations	123			123		
R^2 / R^2 adjusted	0.121 / 0.076			0.055 / 0.007		

Note. CI = Confidence Intervals; *SC* = Switch Cost; *Std* = Standardized.

Table S7 – Worry. Regression Models for Worry as Outcomes and Affective Flexibility as Predictor

	Worry		
Predictors	*Std. Beta*	*Standardized CI*	*p*
Non-Affective Negative SC	0.07	-0.08 – 0.23	0.352
Non-Affective Positive SC	0.03	-0.14 – 0.20	0.739
Affective Negative SC	-0.01	-0.17 – 0.14	0.848
Affective Positive SC	0.00	-0.17 – 0.17	0.994
Gender	0.24	-0.18 – 0.66	0.264
Chronic Stress	0.53	0.37 – 0.69	**<0.001**
Observations	123		
R^2 / R^2 adjusted	0.327 / 0.293		

Note. CI = Confidence Intervals; *SC* = Switch Cost; *Std* = Standardized.

Exposure to acute stressors is considered important for bolstering resilience. However, sustained stress responses to such events can have detrimental long-term effects on both mental and physical health. Research frameworks suggest that executive functioning may be implicated in protecting against excessive stress responses, but research testing this assumption remains limited. The aim of this thesis was two-fold: first, to evaluate the protective role of executive functioning with respect to stress anticipation, reactivity, and recovery; and second, to explore the mediating roles of cognitive and behavioral factors in this association. We found evidence for better executive functioning facets predicting lower subjective and physiological stress responses in ecological settings (examination stress), laboratory settings (acute induced stressor), and in daily life (daily stressors). Given the relevance of cognitive flexibility, we sought to extend these findings to affective flexibility. We discuss the theoretical, methodological, and practical implications for cognitive flexibility and stress regulation.

UCLouvain

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