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THE ROLE OF EXECUTIVE FUNCTIONS IN EMOTION REGULATION

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GENERAL INTRODUCTION

Research problem

Emotion regulation (also referred to as emotion self-regulation) encompasses the processes and strategies that are involved in the modulation of experience and expressions of emotions (Gross, 1998, 2015; McRae & Gross, 2020). The regulation of an emotion could occur at any stage of the emotion trajectory. This could be in the form of down-regulation (aimed at reducing the intensity of emotional experience) or upregulation (aimed at increasing the intensity of emotional experience). Different aspects of emotion could be subjected to some form of regulation such as subjective experience, valence of the emotion, emotional expressions, and physiological responses related to emotions (Gross, 1998).

The ability to regulate emotions cannot be underestimated. This topic has become important considering its role in psychosocial wellbeing. It is well documented that a higher ability to regulate one's emotions is associated with important positive health outcomes such as better mental health and psychosocial wellbeing (Gross, 2014; Tamir, 2016; Verzeletti et al., 2016). Conversely, outcomes of poor emotion regulation are associated with depressive symptoms (Joormann & Stanton, 2016; Visted et al., 2018), poor psychosocial wellbeing (Nasso et al., 2019), and poor mental health (Aldao et al., 2010; Mennin & Farach, 2007).

Although many strategies of emotion regulation are described in the literature, not all are considered adaptive. For instance, rumination (Aker et al., 2014; Besharat et al., 2013; Zawadzki, 2015), worry (Knepp et al., 2015; Neudert et al., 2017), and excessive use of suppression (Appleton et al., 2013; Cai et al., 2019; Nittel et al., 2018) have been considered as maladaptive emotion regulation strategies. Extreme forms of maladaptive strategies, which have both short-term and long-term impacts on physical health, include excessive use of alcohol and drugs (Dvorak et al., 2014; Petit et al., 2015).

The most influential model of emotion regulation is the *process model* by Gross (1998, 2015). This model classifies emotion regulation strategies based on the time-course of emotion generation. The notable distinction is the antecedent-focused strategies (e.g., cognitive reappraisal) and response-focused strategies (e.g., expressive suppression).

The implementation of emotion regulation strategies is considered to have cognitive roots (Schmeichel & Tang, 2015; Suri et al., 2013). It has further been posited that higher cognitive abilities could subserve successful application of emotion regulation strategies (Tull & Aldao, 2015). Hence, cognitive processes which include executive functions are thought to be at the heart of emotion regulation. As a result, more efficient executive functions are expected to result in better emotion regulation outcomes. This argument, however, has received little empirical support so far.

Executive functions (also referred to as cognitive control or executive control) are broadly defined as higher-order cognitive processes that modulate the functioning of the processes at low-level cognition (Friedman & Miyake, 2017; Miyake et al., 2000). Executive functions subserve the control and regulation of thought and action repertoire (Friedman et al., 2006). The prefrontal cortex, caudate nucleus, and subthalamic nucleus (brain regions), which are associated with executive processes, also play a mediating role in inhibitory control (Alvarez & Emory, 2006; Diamond, 2013). Although several models have been developed to explain executive functions, the most acclaimed among them is the *unity-diversity framework* (Miyake et al., 2000), which posits three types of executive functions: updating, shifting, and inhibition.

Several studies investigated the relationship between executive functions and cognitive abilities such as planning (Miyake et al., 2000), maintenance of goals (Kane & Engle, 2003), and dual tasking (D'esposito et al., 1995). Individual differences in executive functions in a healthy population and their role in psychopathology have received considerable attention. Other factors that influence executive functions have been investigated, too. These include the influence of mood on executive functions. For instance, an intense negative emotion undermines inhibitory control, while a milder

negative emotion improves inhibitory control (Pessoa et al., 2012). While negative mood is argued to impair working memory updating (Curci et al., 2013), positive mood facilitates the ability to switch from one task to another, although accompanied by an increased distraction (Dreisbach & Goschke, 2004).

There is paucity of research on the relationship between executive functioning and emotion regulation. Specific ways in which executive functions relate to emotion regulation strategies are poorly understood. This can be attributed to different and not directly comparable operationalizations of executive functions as well as of emotion regulation. In most of the studies, a higher level of updating is positively associated with cognitive reappraisal strategy of emotion regulation but not with expressive suppression (Pe et al., 2013a, 2013b, 2015; Schmeichel et al., 2008). Positive (Liang et al., 2017), negative (McRae et al., 2012), and no association (Malooly et al., 2013; Sperduti et al., 2017) have been reported in the relationship between shifting and emotion regulation strategies. The majority of the studies failed to find a relationship between inhibition and suppression strategy of emotion regulation (Aker et al., 2014; Hendricks & Buchanan, 2016; McRae et al., 2012). One study reported a positive association between inhibition and cognitive reappraisal (Cohen & Mor, 2018). Whereas some studies examined executive functions using affective stimuli (e.g., Pe et al., 2015), others did not (e.g., Hendricks & Buchanan, 2016; Xiu et al., 2016). It can be suggested that since emotion regulation is based on affective information, executive functions that deal with emotional content may be more linked to emotion regulation strategies. Emotion regulation has been assessed using different measures and focusing on strategies which also leads to inconsistent findings (e.g., Gyurak et al., 2012; Sperduti et al., 2017).

The **main aim** of this PhD thesis is to explore the relationship between executive functions and emotion regulation strategies. This includes the development of the non-affective and affective tasks measuring executive functions. This would enable one to understand the extent to which non-affective and affective contents in executive functions

are related to emotion regulation strategies. The thesis further seeks to examine the effectiveness of two main emotion regulation strategies, cognitive reappraisal and expressive suppression, measured via self-report and psychophysiological responses. This would allow one to understand how executive functions contribute to the successful implementation of emotion regulation strategies.

Objectives of the research

1. To analyze the literature on executive functions and emotion regulation.
2. To develop a battery of executive function tasks using affective and non-affective content.
3. To develop experimental procedures for measuring emotion regulation in the laboratory.
4. To compare different measures of the effectiveness of emotion regulation strategies.
5. To examine the relationship between executive functions and emotion regulation.

General hypothesis

Executive functions are the cognitive basis of emotion regulation and therefore predict the successful implementation of emotion regulation strategies.

Specific hypotheses

1. There will be a positive association between executive function processing non-affective and affective content.

2. Reduction of negative emotional state by the emotion regulation strategies would manifest itself in self-report, facial expressions, and autonomic responses.

3. Cognitive reappraisal would result in a larger reduction in negative emotions than in expressive suppression.

4. Updating would be positively associated with cognitive reappraisal.

5. Inhibition would be positively associated with expressive suppression.

6. Shifting ability would be related to more effective use of cognitive reappraisal and expressive suppression.

7. Executive functions processing affective content would be more strongly associated with emotion regulation compared to executive functions processing non-affective content.

Research methodology

Overall, 228[1] participants (mean age = 20.55, SD = 3.41, female = 61.3%) were recruited for the experiments. They were largely student volunteers who took part in the experiments in exchange for course credits. The participants signed informed consent before taking part in the experiments. All experiments were approved by the Institutional Review Board of the Higher School of Economics.

An experimental method was used for the studies. N-back, letter–number, and Stroop tasks were used to measure updating, shifting, and inhibition respectively. Emotion regulation strategies were assessed using an emotion regulation task accompanied by self-reports, electromyography (EMG) of *zygomaticus major* and *corrugator supercilii*, skin conductance response (SCR), heart rate (HR) measurement, and the Gross Emotion Regulation Questionnaire (ERQ). These tasks were carried out at the behavioural and electroencephalography (EEG) laboratories of the Centre for Cognition and Decision Making, Higher School of Economics. The experimental stimuli were obtained largely from two sources, the EU-Emotion stimulus set (O'Reilly et al., 2012, 2015) and the International Affective Picture System (IAPS: Lang et al., 1997).

ActiChamp (Brain Products, Germany), a data collecting system, was used to extract and filter the physiological data during the emotion regulation task.

Statistical analysis included, mixed-design analysis of variance (ANOVA), correlational tests, Friedman's analysis, Benjamini and Hochberg's (1995) correction for

[1] This is comprised of 84 in Chapter 2, 64 in Chapter 3, 63 and 81 in Chapter 4. However, the sample in Chapter 3 was part of the sample in Chapter 4, Study 2.

false discovery rate, Cliff's δ (Cliff, 1993), and *t*-tests. The statistical tests were carried using IBM SPSS 21.0, JASP 0.13.1.0, and STATISTICA 12.

Scientific novelty

The PhD thesis makes a contribution to further scientific knowledge on mechanisms of emotion regulation. Attempts were made in the past to examine the relationship between executive functions and emotion regulation which produced inconsistent findings. The current thesis extends this knowledge by fine-tuning the operationalization of these concepts to understand how executive functions contribute to emotion regulation success. Thus, for the first time, executive functions were measured using tasks containing non-affective and affective content. This led to the development of a new battery of tasks measuring executive functions. Although Pessoa (2009) posited that affective content in tasks does have an impact on executive functioning, this was not supported in the present research. Hence, the present findings support the view that affective content in these tasks does not influence performance in a healthy population (cf. Schweizer et al., 2019).

Emotion regulation strategies were also examined using multiple measures. Self-reports, measures of peripheral psychophysiology, and questionnaires were among the methods used. Since the experience and expression of emotions can be observed via self-report and psychophysiological responses, the emotion regulation strategies were assessed from these outcomes as well. The current findings add to what is already known on the association between executive functions and emotion regulation. The evidence of the positive association between updating and cognitive reappraisal supports the growing body of research that reported similar results. For the first time, the ability to inhibit automatic responses was demonstrated to be related to the frequent use of suppression of emotional expression. The results provided further evidence that emotion regulation strategies differ based on the measure used during the assessment. Within the framework of the *process model* of emotion regulation (Gross, 1998), the current findings contribute to the distinction between cognitive reappraisal and expressive suppression. Self-reported

unpleasant emotion was shown to be reduced in a greater extent by cognitive reappraisal than by expressive suppression. These findings could explain the previous inconsistent findings on the relationship between executive functions and emotion regulation.

The **theoretical significance** of this research is the contribution to the refinement of existing theories such as the *dual-competition* framework (Pessoa, 2009) and the *process model* of emotion regulation (Gross, 1998). According to the *dual-competition* framework (Pessoa, 2009), executive functions are influenced by affective content. However, based on the results of the present research and recent studies (e.g., Schweizer et al., 2019), it is suggested that the influence of affective content in executive functioning is not prevalent in a healthy population but in individuals with affective disorders. According to the *process model* of emotion regulation (Gross, 1998), cognitive reappraisal and expressive suppression differ according to their temporal application and their consequences. This distinction has received empirical support across multiple measures.

The **practical implication** of the research is a potential application of the present findings in clinical psychology, cognitive psychology, and cognitive neuroscience as well. The present findings would also be important for the content of future textbooks or manuals in these areas. As executive functions and emotion regulation feature in these areas, the present findings could be incorporated into what is already known about these topics and their relationship. As higher inhibitory control leads to successful implementation of suppression, the training on inhibition could help improve suppression in emotion regulation. Clinicians, in their efforts at helping people with emotion dysregulation, could resort to training programs aimed at improving executive functions. Hence, one possible target for improving emotion regulation is executive functions.

Statements for the defense

1. Some executive functions can be considered as the cognitive basis of emotion regulation. Updating is positively associated with the effectiveness of the cognitive reappraisal strategy of emotion regulation, whereas inhibition is positively

associated with the frequency of the use of the expressive suppression strategy of emotion regulation.

2. Cognitive reappraisal and expressive suppression are effective in downregulating negative emotion. However, the effectiveness of emotion regulation strategies manifests itself differently depending on the type of measures used for assessment. Differences between cognitive reappraisal and expressive suppression are greatest in self-report and heart rate deceleration measures.
3. Executive functions, namely updating, shifting, and inhibition, do not differ with respect to affective and non-affective content. Non-affective and affective measures of executive functions yield similar patterns of associations with measures of emotion regulation strategies.

Approbation and introduction of results

The outcome and content of this research were discussed at various seminars and scientific conferences, as listed below.

Conferences:

1. Society for Affective Science virtual meeting – Gater.Town. April 13-16, 2021. Oral presentation: The role of executive functions in emotion regulation.
2. Society for Affective Science virtual meeting – Gater.Town. April 13-16, 2021. Oral presentation: Emotion regulation strategies depending on empathy: Psychophysiological study.
3. International forum, Cognitive neuroscience. December 11-12, 2020, Yekaterinburg, Russia. Poster presentation: The role of executive functions in emotion regulation.
4. Psy-HSE: Conference of Young Scientists. Contemporary Issues of Psychological Science. October 31-November 2, 2019. Moscow, Russia. Oral presentation: Individual differences in executive functions and emotion regulation.

5. International Society for Research on Emotion. July 10-13, 2019. Amsterdam. Flash talk and poster presentation: Updating of emotional stimuli in working memory: The role of mood and emotion regulation.

6. 5th Conference “Cognitive Science in Moscow: New Research”. July 19, 2019. Poster presentation: The role of induced mood and emotion regulation in updating of valenced information.

The content of the dissertation is presented in three published articles. They are listed below:

1. Mohammed, A.-R., Kosonogov, V., & Lyusin, D. (2021). Expressive suppression versus cognitive reappraisal: Effects on self-report and peripheral psychophysiology. *International Journal of Psychophysiology, 167,* 30-37. https://doi.org/10.1016/j.ijpsycho.2021.06.007

2. Mohammed, A.-R. & Lyusin D. (2020). The role of affective updating in the cognitive reappraisal strategy of emotion regulation. *Psychological Thought*, *13*(2), 302-321. https://doi.org/10.37708/psyct.v13i2.515

3. Mohammed, A.-R. (2019). A battery of cognitive tasks for the assessment of non-affective and affective executive functioning. *The Russian Journal of Cognitive Science*, *6*(3), 38-49.

Structure of the dissertation

Chapter 1 includes the review of the present literature on executive functions and emotion regulation including their assessments. Chapter 2 describes the development and analysis of the new battery of tasks measuring non-affective and affective executive functions. Chapter 3 presents the assessment of the effectiveness of emotion regulation strategies. Chapter 4 describes the study of the relationship between executive functions and emotion regulation. A summary of the findings and the general discussion including the conclusions were also provided.

SUMMARY OF MAIN CHAPTERS

Each of the four empirical studies aimed to clarify the nature of executive functions and emotion regulation and the specific ways they are related. Specifically, the research questions that were intended to be answered in the various chapters of the thesis were:

1. What are the theoretical underpinnings of executive functions and emotion regulation? What is the current state of the literature on the association between executive functions and emotion regulation? (Chapter 1);
2. Does affective content in the tasks measuring executive functions influence the performances of executive functions? Does it occur across all executive functions or is it peculiar to specific executive functions? (Chapter 2);
3. How effective are cognitive reappraisal and expressive suppression strategies? What is the comparative effectiveness of these strategies when assessed via self-report and psychophysiological measures? Specifically, do the emotion regulation strategies show similar outcomes as manifested in self-reports and psychophysiological responses? (Chapter 3);
4. What is the relationship between executive functions and emotion regulation strategies? Will measures of executive functions in affective tasks be more related to emotion regulation strategies; or the affective content in the executive functions task does not matter in this relationship? (Chapter 4).

In **Chapter 1** of the dissertation, a thorough review of the literature was conducted. The concept of emotion regulation was examined including the motives for emotion regulation, common emotion regulation strategies, models, and theories of emotion regulation. The reviewed theoretical models of emotion regulation included the strategy-based models (Aldao et al., 2010; Aldao & Dixon-Gordon, 2014; Aldao & Nolen-Hoeksema, 2012; Naragon-Gainey et al., 2017; Parkinson & Totterdell, 1999; Tang & Huang, 2019), ability-based models (Berking & Whitley, 2014; Gratz & Roemer, 2004; Law et al., 2015; Tull & Aldao, 2015; Radkovsky et al., 2014; Roemer et al., 2015) and the

temporal process of emotion regulation (i.e., the process model by Gross, 1998; 2015; Naragon-Gainey et al., 2017).

The *process model* of emotion regulation (Gross, 1998, 2015) was considered as the working model for the thesis based on its comprehensive conceptualization of the emotion regulation strategies. There was a special focus on the measures of the effectiveness of emotion regulation strategies. The review aimed to better understand how effective cognitive reappraisal (antecedent-focused) and expressive suppression (response-focused) strategies of emotion regulation are, as captured by various measures. It was observed that in previous research, inconsistent findings characterized the effectiveness of cognitive reappraisal and expressive suppression. This was attributed to the measures used for the assessment.

The concept of executive functions was also explored in the literature. The common executive functions in the literature were examined including several theoretical models. The models of executive functions featured the Baddeley's *working memory model* (Baddeley, 2003; Baddeley & Hitch, 1974), the *supervisory attention system* (Andrés & Van der Linden, 2000; Hommel et al., 2002; Norman & Shallice, 1980), and the *unity-diversity framework* (Friedman & Miyake, 2017; Miyake et al., 2000). Although the models explained the concept of executive functions, the *unity-diversity framework* was more precise by showing how three specific executive functions are separate at the component level but unite to form a complex executive functions model. These executive functions are updating, shifting, and inhibition. Hence the present thesis focused on the *unity-diversity framework* as the working model of executive functions. Representative tasks measuring specific executive functions were highlighted as well.

The review also included empirical studies conducted on executive functions processing non-affective and affective materials. This was undertaken to better understand the extent to which non-affective and affective content influence performances in executive functions. It was observed that affective content has influence on task performance, but the effect was found in studies of mood-related disorders and cognitive tasks (Pessoa, 2009;

Schweizer et al., 2019). Knowledge of executive functions specifically related to affective and non-affective content in a healthy population is hardly available.

The final review focused on the relationship between executive functions (i.e., updating, shifting, and inhibition) and emotion regulation strategies (cognitive reappraisal and expressive suppression). In most of the studies, a higher level of updating is positively associated with cognitive reappraisal strategy of emotion regulation but not with expressive suppression (Pe et al., 2013a, 2013b, 2015; Schmeichel et al., 2008). Positive (Liang et al., 2017), negative (McRae et al., 2012), and no association (Malooly et al., 2013; Sperduti et al., 2017) characterized the relationship between shifting and emotion regulation strategies. The majority of the studies failed to find a relationship between inhibition and suppression strategy of emotion regulation (Aker et al., 2014; Hendricks & Buchanan, 2016; McRae et al., 2012). One study reported a positive association between inhibition and cognitive reappraisal (Cohen & Mor, 2018). In general, it is unclear whether affect could play a role in the association between executive functions and emotion regulation strategies.

In **Chapter 2**, a new battery of tasks measuring non-affective and affective executive functions is described. This was to achieve a wider goal to understand whether non-affective or affective executive functions are more related to emotion regulation outcomes. The n-back task (n = 2), letter–number task, and the Stroop task were used to measure updating, shifting, and inhibition respectively. Each task had both non-affective and affective versions. The battery of the executive function measures was designed in such a way that in both the non-affective and affective tasks the same procedure was employed, including equal number of trials, duration of stimulus presentation, and inter-trial interval. Based on the pattern of results in the previous studies, the following hypothesis was stated.

H1: There will be a positive association between executive functions processing non-affective and affective content.

Method: Eighty-four student volunteers participated in the experiment (51 % female). The average age was 19.3 (SD = 2.1). Participants completed non-affective and affective versions of the n-back task (n = 2), letter–number task, and the Stroop task. While the non-affective tasks were made up of letters, numbers, and colours, the affective tasks had pictures obtained from the EU-Emotion stimulus dataset (O'Reilly et al., 2012, 2015). A within-subject design was used for the experiment. Due to equipment breakdown and withdrawal of some participants, the final data processed for analysis were n-back task = 79, letter–number task = 79, and the Stroop task = 80.

Results: No mean differences were found between the non-affective and the affective 2-back task for accuracy ($t(78) = .07$, $p = .95$, $d = .01$) and RTs ($t(78) = 1.71$, $p = .09$, $d = .19$). This pattern was also extended between non-affective and affective shifting cost ($t(78) = .28$, $p = .78$, $d = .03$) and cost of inhibition ($t(79) = .99$, $p = .33$, $d = .11$). This suggests that non-affective and affective tasks measuring these executive functions do not differ in measures of performance. In addition, there is a positive correlation between performance in the non-affective and the affective 2-back task using accuracy ($r(79) = .65$, $p < .001$) and RTs ($r(79) = .55$, $p < .001$) and letter–number task ($r(79) = .38$, $p < .001$), except in the case of inhibition ($r(80) = .13$, $p = .19$). Overall, we see that the performance in tasks measuring the executive functions are not impacted by the content type.

Discussion: The results support the hypothesis about the existence of a positive association between non-affective and affective content in executive functions, except inhibition. Additionally, we observed that the differences between non-affective and affective executive functions were not statistically significant. The pattern of results obtained was largely expected due to the nature of the tasks (both non-affective and affective tasks). To process the affective information would require extra resources due to the additional demand to identify the emotion by observing all potential cues from the face. This is different from the processing of non-affective stimuli. For example, in the n-back task, the participant had to just identify the letter in the task whereas, in the affective version, the perceptual information of the face is richer, which would demand more time to

complete. The medium correlations observed in the non-affective and the affective versions of the n-back and letter–number tasks suggest that both versions measure different although related aspects of the executive functions.

In **Chapter 3**, an examination of the measures of cognitive reappraisal and expressive suppression was carried out. This was necessary due to the inconsistent findings about the effectiveness of emotion regulation strategies in the literature (Hendricks & Buchanan, 2016; Livingstone & Isaacowitz, 2018; Lohani & Isaacowitz, 2014; Urry, 2009; Witvliet et al., 2011). The study assessed the effectiveness of the strategies as captured via self-report, facial expressions (EMG of *corrugator supercilii* and *zygomaticus major*), and autonomic responses (SCR and HR). It was envisaged that the deployment of these multiple measures would help address the inconsistencies in the assessment of emotion regulation strategies in previous research. Notably, this would allow the examination of a singular emotional responding as captured by the deployment of the multiple measures. As posited by the process model of emotion regulation (Gross 2002, 2015), the latter stage of emotion generation as manifested in three components (i.e., experiential, behavioural, and physiological reaction) could be impacted by these emotion regulation strategies. Thus, the deployment of multiple measures would tap into each of the components. This would enable one to appreciate the consistency (or discrepancy) between these measures or whether some would be more sensitive than others. The following hypotheses were stated.

H1: Reduction of negative emotional state by the emotion regulation strategies would manifest itself in self-report, facial expressions, and autonomic responses.

H2: Cognitive reappraisal would result in a larger reduction in negative emotions than in expressive suppression.

Method: Sixty-four participants (67.2% females) were recruited for the experiment. The mean age was 20.85 (SD = 3.82). A within-subject design was used for the study. In the emotion regulation task, participants were presented with neutral or intense unpleasant negative pictures and asked to rate how negative they felt after viewing each picture. The

pictures were presented under three instructions; look, suppress or reappraise. Participants psychophysiological responses were also recorded during the task.

Results: (1) Self-report. Cognitive reappraisal ($t(62) = 10.88$, $p < .001$, $\delta = .29$) and suppression to negative pictures ($t(62) = 8.07$, $p < .001$, $\delta = .20$) resulted in lower ratings of negative emotional state compared to absence of regulation. Reappraisal resulted in lower ratings of negative emotional state than suppression ($t(62) = 2.81$, $p = .006$, $\delta = .10$). **(2) Zygomaticus major EMG.** There was no difference in zygomaticus major EMG between reappraisal, suppression and looking at negative pictures ($ts < 0.42$, $ps > .14$, $\delta s < .08$). **(3) Corrugator supercilii EMG.** There was a greater activity in corrugator supercilii EMG during the presentation of negative pictures than reappraisal ($t(62) = 4.34$, $p < .001$, $\delta = .25$) and suppression to negative pictures ($t(62) = 4.26$, $p < .001$, $\delta = .32$). The difference between reappraisal and suppression to negative pictures was not statistically significant ($t(62) = 0.08$, $p = .94$, $\delta = .05$). **(3) SCR**. There was a larger SCR during the presentation of negative pictures than reappraisal to negative pictures ($t(62) = 2.94$, $p = .004$, $\delta = .21$). Reappraisal, suppression and looking at neutral pictures were not statistically different ($ts < 1.08$, $ps > .28$, $\delta s < .10$). **(4) HR 1-3 s.** The results showed suppression evoking larger HR deceleration (i.e., larger reduction in beats) than looking at negative pictures ($t(62) = 2.70$, $p = .008$, $\delta = .22$), neutral pictures ($t(62) = 4.00$, $p < .001$, $\delta = .35$) and reappraisal of negative pictures ($t(62) = 2.70$, $p = .008$, $\delta = .22$). Reappraisal of negative pictures and looking at neutral or negative pictures were not statistically different ($ts < 1.28$, $ps > .20$, $\delta s < .14$). **(5) HR 4-6 s.** The outcomes showed that suppression resulted in greater HR deceleration compared to looking at neutral pictures ($t(62) = 4.17$, $p < .001$, $\delta = .43$), and looking at negative pictures ($t(62) = 2.42$, $p = .017$, $\delta = .27$). Looking at negative pictures, neutral pictures and reappraisal were not statistically different from each other ($ts < 1.85$, $ps > .07$, $\delta s < .18$).

Discussion: The first hypothesis on the reduction of negative emotional state assessed with the multiple measures was supported. The difference between cognitive reappraisal and expressive suppression was found in self-report and HR deceleration. This

partially supports the second hypothesis. Both EMG and SCR showed that looking at negative pictures elicited the experience of more negative emotion than the emotion regulation strategies but revealed no difference between cognitive reappraisal and expressive suppression. The different patterns of results obtained between the psychophysiological measures used are not surprising. In the case of self-report, one could interpret that the participants were just following the instructions, but when these results are supported by the data from the psychophysiological responses, it suggests that the participants had indeed experienced the emotion. The present findings contribute to the distinction between cognitive reappraisal and expressive suppression within the context of the *process model* of emotion regulation (Gross, 1998). Cognitive reappraisal led to a larger mitigation of self-reported negative emotion than expressive suppression. This could mean that cognitive reappraisal exerts a direct elaboration of the content at the conscious level, such as interpretation or thoughts. Thus, cognitive reappraisal was more successful for the change of subjective experience since it is less cognitively costly. In comparison, psychophysiological responses showed no differences in the emotion regulation strategies studied.

In **Chapter 4**, the specific ways through which executive functions relate to emotion regulation strategies were investigated. Two experiments were carried out. **Study 1** investigated the relationship between affective updating (using the n-back task) and cognitive reappraisal strategy of emotion regulation (using the Gross ERQ).

H1: Updating of affective information should be positively associated with the cognitive reappraisal strategy of emotion regulation.

Sixty-three (63) participants (female = 61%; mean age = 21.31, *SD* = 4.03) took part in the experiment. While an affective n-back task (load factor = 2) was used to assess updating, the Russian adaptation of the Gross ERQ was used to assess emotion regulation Gross & John, 2003; Pankratova & Kornienko, 2017). The results showed mean accuracy was positively related to cognitive reappraisal strategy ($r(57) = .288$, $p = .027$). This

implied that higher accuracy in the 2-back task was associated with higher scores in cognitive reappraisal, thus supporting the hypothesis of the study.

In **Study 2,** the relationship between the three executive functions and the two emotion regulation strategies was examined. The n-back, letter–number, and the Stroop tasks were used to measure updating, shifting, and inhibition respectively. Cognitive reappraisal and expressive suppression were assessed by the use of questionnaires and the presentation of short neutral and negative pictures in the laboratory; participants were asked to implement the emotion regulation strategies.

H1: Updating would be positively associated with cognitive reappraisal.

H2: Inhibition would be positively associated with the expressive suppression strategy of emotion regulation.

H3: Higher shifting ability would be related to more effective use of cognitive reappraisal and expressive suppression.

H4: Executive functions processing affective content would be more strongly associated with emotion regulation compared to executive functions processing non-affective content.

The study recruited 81 healthy student volunteers (Female = 68.4%; mean age = 20.32, *SD* = 3.68). Participants completed a battery of executive function measures (i.e., n-back, letter–number and Stroop tasks) and emotion regulation measures (i.e., emotion regulation task and the Gross ERQ). The final sample for all measures were n-back task 78, letter–number task 78, Stroop task 79, self-report ratings 79, zygomaticus major EMG 78, corrugator supercilii EMG 78, SCR 78, and HR measure 78.

The results showed that faster performance in the non-affective updating task was positively associated with a greater change in HR deceleration during the application of cognitive reappraisal (r_s (77) = -.249, p = .029). This meant that efficient updating was related to a more positive outcome of cognitive reappraisal reflected by HR deceleration. Thus, the first hypothesis was partially supported. The greater cost of inhibition related to

non-affective stimuli led to a greater reduction of zygomaticus EMG during suppression (r_s (77) = .254, p = .026).

The results on inhibition and suppression showed positive correlations between the cost of inhibition and suppression on the one hand (r_s (79) = .246, p = .029), and the cost of affective inhibition and suppression on the other hand (r_s (79) = .264, p = .018). This suggests that inhibition of non-affective or affective content was related to the higher frequency of the use of expressive suppression. This supports the second hypothesis. The third hypothesis on the positive association between shifting and the two emotion regulation strategies was not supported. A possible explanation is that shifting involves other cognitive processes. Finally, it was observed that affective and non-affective executive functions did not differ in their relationships with emotion regulation strategies. This means that the fourth hypothesis was not supported. This could be explained by the finding that affective content does not influence executive functions in a healthy population.

Overall, both studies support the idea that higher performance in executive functions is partially associated with the successful implementation of emotion regulation strategies. Particularly, updating was positively related to cognitive reappraisal. Inhibition of non-affective and affective content is associated with a higher frequency of the use of expressive suppression. The content of the tasks when measuring executive functions does not play a role in the association between executive functions and emotion regulation strategies.

GENERAL DISCUSSION AND CONCLUSIONS

To have a general insight into the research questions formulated above, the literature reviewed provided more information on the existing studies of executive functions and emotion regulation (Chapter 1), this led to the development of a new battery of tasks measuring executive functions processing non-affective and affective information (Chapter 2). An experiment was also conducted on the effectiveness of emotion regulation strategies using self-report and psychophysiological responses (Chapter 3). This allowed to directly estimate the relationship between executive functions and emotion regulation strategies (Chapter 4).

Main findings and conclusions from the empirical studies

The main findings on executive function processing non-affective and affective content were reported in Chapter 2. No mean differences were observed between the performance related to non-affective and affective versions of updating, shifting, and inhibition tasks. Medium positive correlations between the non-affective and affective versions of the updating and inhibition tasks were also observed. This suggests that both versions capture similar psychological constructs (i.e., executive functions), although they are not identical. The results of the study do not support the *dual-competition framework* (Pessoa, 2009) which posits that affective content influences executive functions.

In Chapter 3, a comparison of the measures of the emotion regulation strategies was carried out. Specifically, self-reports and psychophysiological measures of cognitive reappraisal and expressive suppression were examined. The difference between cognitive reappraisal and expressive suppression was observed only in self-report and HR deceleration. In all the measures used to assess emotion regulation strategies, different patterns of the effectiveness of the emotion regulation strategies were observed. This suggests that the use of multiple measures in the assessment of emotion regulation strategies would be more appropriate.

The main findings on the relationship between executive functions and emotion regulation are reported in Chapter 4. The two experiments showed that higher updating of

affective information was related to the cognitive reappraisal strategy of emotion regulation. Inhibition was associated with the more frequent use of expressive suppression. Shifting was associated with neither cognitive reappraisal nor expressive suppression. Finally, the affective content of the tasks when measuring executive functions did not influence the relationship between executive functions and emotion regulation strategies.

A novel battery of executive functions tasks with non-affective and affective content was created. Although the individual tasks were not new, there is no existing battery of tasks that measures updating, shifting, and inhibition by incorporating non-affective and affective content in these tasks. The novel battery contained the n-back, letter–number, and Stroop tasks.

The present thesis provided data on the outcome of emotion regulation strategies measured via self-reports, behavioural and psychophysiological responses. We were able to observe how a singular emotional reaction is manifested via self-reports, facial expressions (EMG of corrugator supercilii and zygomaticus major), and autonomic responses (SCR and HR). The data also showed that there is greater HR deceleration during the suppression of negative emotions. The assessment of the effectiveness of emotion regulation strategies in previous studies failed to examine the outcome in the three main pathways of emotional expressions (i.e., experiential, behavioural, and physiological reaction).

Unlike previous studies, the present research examined the relationship between executive functions and emotion regulation by using both non-affective and affective tasks measuring executive functions. This made it possible to investigate whether non-affective or affective tasks measuring executive functions are more related to emotion regulation. For the first time, inhibition was found to be positively associated with the frequent use of the expressive suppression strategy of emotion regulation.

Limitations and recommendations for further studies

Even though the thesis has made contributions to the understanding of the relationship between executive functions and emotion regulation, the study has some

limitations. The sample consisted largely of undergraduate students and younger adults. Hence the findings must be interpreted with caution since they cannot be directly generalized to children and older adults. The samples in the experiments were largely female. Further experiments targeting other groups (i.e., older adults, children) would help one to understand the extent to which the present findings could be replicated.

The behavioural tasks used for measuring executive functions have limitations as well. Low arousal affective stimuli were used in the affective versions of the tasks. It is unclear whether high-arousal affective stimuli could produce a similar pattern of results. Hence it would be interesting to see a future study using highly arousing stimuli in the tasks measuring the executive functions.

Although the implementation of emotion regulation strategies can be implicit or explicit, only the latter was deployed throughout the research. The use of explicit emotion regulation in the laboratory, despite its inherent benefits, could be influenced by demand characteristics. The advantage of explicit emotion regulation strategy in the laboratory is that the experimenter is able to record the timepoint at which a strategy is initiated and disengaged. This also helps to observe the immediate outcome of the implementation of the emotion regulation strategy. However, the adoption of the explicit emotion regulation strategy could result in some participants merely following the instructions and responding in the way that would appear desirable. Implicit emotion regulation, which occurs naturally and unconsciously, could help explain how executive functions serve as a cognitive basis of emotion regulation. It would therefore be recommended that future research considers using implicit emotion regulation strategies in the laboratory.

Moving forward, future experiments could address these limitations and employ experimental designs that would help to shed more light on the relationship between executive functions and emotion regulation. This would help expand this interesting and highly relevant topic in improving individuals' wellbeing.

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