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The ability to exert influence on our emotions play a significant role in the attainment of our goals. To have control over when and how we experience emotions are thought to be impacted by higher cognitive processes such as executive functions. However, there is inadequate research to support this notion. Hence, we examined the relationship between executive functions – updating, shifting and inhibition – and emotion regulation strategies – cognitive reappraisal and expressive suppression. We predicted that higher updating would positively relate to cognitive reappraisal, while inhibition would positively relate to expressive suppression. We further hypothesized that shifting would positively relate to both cognitive reappraisal and expressive suppression. Participants completed updating, shifting and inhibition tasks. Then they used expressive suppression or cognitive reappraisal strategies in response to unpleasant pictures, accompanied with physiological recording. Faster updating was associated with a larger heart rate deceleration during reappraisal. Inhibition was associated with a more frequent use of suppression. Overall, these data confirm the idea that a higher level of executive functions is partially related to the efficient application of emotion regulation strategy. As to other physiological measures, although typical patterns of emotional responding were observed, they did not correlate with the executive function measures during emotion regulation.

JEL Classification: Z

Key words: executive functions, cognitive reappraisal, expressive suppression, emotion regulation, heart rate, skin conductance, EMG, updating, shifting, inhibition.

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Introduction

Emotion regulation (ER) refers to the various attempts aimed at influencing the experience and expression of emotions (Gross, 1998; 2015; McRae & Gross, 2020). As ER is multifaceted, different aspects of emotion trajectory such as the experience and expressions could be a subject of regulation. The regulation of an emotion plays an important role in the attainment of goals. It has been well documented that ER plays a significant role in psychosocial wellbeing and greater mental health (Gross 2014; Tamir, 2016; Verzeletti et al., 2016).

An influential model of ER, the process model, posited five families of ER strategies based on the modal model of emotion generation (Gross, 1998; 2015; McRae & Gross, 2020). These families are situation selection, situation modification, attentional deployment, cognitive change, and response modulation. Among the ER strategies, cognitive reappraisal (example of cognitive change) and expressive suppression (example of response modulation) have received greater attention in research (Gross, 2015; McRae & Gross, 2020).

Cognitive reappraisal is the deliberate attempt to alter the meaning of an emotional content or stimuli, to make it less impactful (Gross, 2001; Gross & John, 2003). Several approaches have been used such as focusing on the positive aspect of the unpleasant stimuli, distracting oneself from the stimuli, develop a fictitious interpretation of the stimuli or distancing oneself from the real meaning of the stimuli. Expressive suppression, on the other hand, occurs at the latter stage of the emotion generation process where there is the deliberate attempt to inhibit an ongoing emotional experience (Gross, 2001; Gross & John, 2003). Emotion has three facets; experiential, behavioral and physiological activations, and each of them could be subjected to some form of suppression. The use of these ER strategies is believed to have cognitive underpinnings (Schmeichel & Tang, 2015). That is, cognitive processes such as executive functions (EF) are believed to serve as the foundation of ER. Therefore, an efficient EF should lead to better ER outcome, an idea that has not received enough empirical attention. To address the gap in the literature, the present study seeks to examine the role of EF in the effective use of ER strategies.

EF are higher order cognitive mechanisms that modulates the functioning of the lower cognitive process and as well influences the control of behavior (Jurado & Rosselli, 2007; Miyake et al., 2000). One popular model of EF is the *unity-diversity framework* which summarizes EF into three; namely, updating, shifting and inhibition (Friedman & Miyake, 2017; Miyake et al., 2000). Thus, of the many EF that have been reported, they are connected to one of the summarized EF at the component level, and together they make up a complex EF model. Hence, here we narrow EF to updating, shifting and inhibition.

1.1 Updating and emotion regulation

Updating refers to the monitoring and manipulation of incoming information relevant to the present task and replacing no longer needed old information with newer and relevant content (Baddeley, 2003; Miyake et al., 2000; Morris & Jones, 1990). Although attempts have been made to examine how EF relates to ER, not much is known about the relative contribution of these three EF in the successful implementation of ER strategies. Cognitive reappraisal has been thought to be more strongly associated with updating compared to suppression. Some studies reported positive associations between updating and cognitive reappraisal (Hendricks & Buchanan, 2016; Mohammed & Lyusin, 2020; Pe et al., 2015; Sperduti et al., 2017), whereas others found no associations (Gyurak et al., 2012; Hoorelbeke et al., 2016). It is worth noting that most studies measured updating using non-affective stimuli (e.g., Hendricks & Buchanan, 2016; Xiu et al., 2016), although some used affective content in the updating task (e.g., Mohammed & Lyusin, 2020; Pe et al., 2015).

1.2 Shifting and emotion regulation

Shifting involves the ability to shift between or among mental sets or operations (Miyake et al., 2000). The capacity to shift between multiple tasks and mental sets is important for ER outcomes due to the everchanging emotional contexts. For both cognitive reappraisal and expressive suppression, there has generally been mixed findings. Some reported positive associations, that is the greater the performances in shifting, the more effective is cognitive reappraisal (e.g., Liang et al., 2017) in an elderly population and expressive suppression (e.g., Hendricks & Buchanan, 2016). Negative associations (McRae et al., 2012) and no associations (e.g., Malooly et al., 2013; Sperduti et al., 2017) have also been reported between shifting ability and ER.

1.3 Inhibition and emotion regulation

Inhibition is the ability to inhibit automatic responses when needed (Aker & Landrø, 2014). The association between inhibition and ER has not received considerable attention, compared to updating. The ability to inhibit prepotent responses should contribute to the effectiveness of the use of expressive suppression strategy of ER. Emotional expression is widely considered to be automatic. It will therefore require some efforts to control emotional expression. Hence, it is expected that inhibition and suppression should relate in the same direction, although there is inadequate empirical evidence to support this view. Previous studies which examined the link between inhibition and cognitive reappraisal reported no association (for a complete review, see Pruessner et al., 2020). On inhibition and suppression, the few studies (Hendricks & Buchanan, 2016) found no link between inhibition and ER, but one study found that better performances in inhibition task was related to higher ER after training (Cohen & Mor, 2018).

1.4 The present study

The present study sets out to examine the role of EF in ER strategies. An important novel feature of the study was the use of affective and non-affective stimuli in the tasks examining EF. The studies mentioned above mostly used the traditional EF tasks with non-affective stimuli. It has been demonstrated that performances in EF tasks can be influenced by the content of the task, i.e., whether it is affective or not. Besides the *dual competition framework* (Pessoa, 2009), which suggests the impact of affective content on EF tasks, empirical studies (e.g., Veroude et al., 2013) have also supported this claim. A recent meta-analytic study (Schweizer et al., 2019) on the relationship between non-affective and affective working memory tasks showed significant difference in performance among patients with mental health problems. Additionally, the non-affective and affective working memory tasks also recruited partially different pattern of brain networks (Schweizer et al., 2019). Thus, differences in tasks performances (non-affective versus affective) could partially account for the association between EF and ER, a view which has not received empirical attention. Hence, it is crucial to examine the role of non-affective and affective EF tasks on cognitive reappraisal and expressive suppression.

Another special feature of the present study is the measurement of three EF and two ER strategies in one experiment. Moreover, ER strategies were measured by two different methods, laboratory ER task and a questionnaire. We first presented three EF tasks (n-back, letter-number and Stroop tasks) followed by an ER task and Gross ER questionnaire. To assess the effectiveness of ER strategies (i.e., cognitive reappraisal and expressive suppression), an ER task was developed where participants were presented with neutral and unpleasant pictures, asked to implement an ER strategy and then rate the degree of how negative they felt. We also added some psychophysiological measurements. Corrugator supercilii and zygomaticus major electromyography (EMG), heart rate (HR) deceleration and skin conductance response (SCR) were assessed. These additional measures were included to ensure a robust assessment of emotional changes during the ER task and, therefore, the effectiveness of ER strategies. Since the processes involved in cognitive reappraisal would involve the reinterpretation of the emotional stimuli, we hypothesized that higher updating functions will be more related to cognitive reappraisal than expressive suppression. Furthermore, based on the mechanisms involved in shifting (i.e., inhibiting interference from the previous task, shift between mental sets), we predicted that shifting would be positively related to both cognitive reappraisal and expressive suppressions. As emotional expression is considered automatic and its inhibition requires some efforts, we hypothesized that inhibition would be positively related to expressive suppression.

Method

2.1 Participants

Eighty-one healthy, volunteers (68.4% females) participated in the experiment[5]. The mean age was 20.32 (*SD*=3.68). Data from 2 participants were excluded due to equipment malfunctioning resulting in a final sample size being 79. The study was carried out in accordance with the declaration of Helsinki and was approved by the institutional review board of the Higher School of Economics. Each participant provided a written consent for their participation in the study.

[5] To determine the sample size, a power analysis was conducted. With a power of 80%, a medium correlation of 0.3 and an alpha of 0.05 and one-tailed test, it resulted in a sample size of 64. In order to avoid potential incomplete data from the experiment, we recruited 81 participants.

2.2 Materials

The pictures from the EU-Emotion stimulus set (O'Reilly et al., 2012; O'Reilly et al., 2015) were used for the EF tasks. The stimulus set is made up of pictures with actors of different age and sex expressing different emotions. Both negative and positive facial expressions were selected from the 'anger', 'disgust', 'elation', 'happy', 'bored' 'kind' and 'sad' categories.

2.2.1 Executive function tasks

N-back task

The detailed description of the EF tasks used in the present study has been reported in a previous study (Mohammed, 2019). The *n*-back task (with $n = 2$) was used to measure updating of information. (Jaeggi et al., 2010; Kirchner, 1958; Levens & Gotlib, 2010; Pe et al., 2013; Rączy & Orzechowski, 2019). This task is carried out by comparing the present stimulus with the stimulus presented two steps back. The load factor of 2 has been shown to demonstrate individual differences in updating ability (Gajewski et al., 2018). In the present experiment, a stimulus was displayed on the screen for 2500 ms with an intertrial interval of 500 ms. The participant was required to compare the present stimulus with the stimulus presented two steps back. One key was pressed if the two stimuli were same while another key was pressed if they were different. In the non-affective task, vowels and consonants were used as stimuli. Thus, the compared stimuli were considered same if they were both vowels or consonants, but different if one was vowel and the other was consonant. In the affective version of the task, both negative and positive facial expressions were used. One key was pressed if the compared faces were same (either both positive or both negative), while another key was pressed if they were different (one is positive and the other negative). Participants began with 16 practice trials followed by 82 quasi-randomized trials in the main experiment. Accuracy rates and response time (RT) were recorded.

Letter-number task

To assess shifting, the letter-number task was used. This involves presenting a pair of a letter and a number (e.g., A5) and asking participants to respond to either the letter or number depending on the condition (Monsell, 2003; Rogers & Monsell, 1995). In the present experiment, the pair of letter and number appeared at any of the quadrant on the screen. If the pair appeared at the top quadrant, the participant responded whether the letter was a vowel or consonant. When it appeared at the bottom, the participant responded to the number by indicating that it was an odd or even number. Three blocks of trials were presented. In the first block, the pair of number and letter appeared at the top quadrant (could be left or right) while in the second block, it appeared at the bottom quadrant (either left or right). The third block had the pair appearing in a clockwise direction. In the affective version, emotional facial expressions were used instead of the letter-number pair. When the picture appeared in the top quadrant, the participant responded to the sex of the actor in the picture. If the picture appeared at the bottom the participant responded to the valence of the emotional expression. In both the non-affective and the affective letter-number tasks, the first and second blocks had 32 trials each, while the final block had 128 trials. All trials were quasi-randomized. Accuracy rates and RT were recorded for each trial.

Stroop task

The Stroop task (MacLeod, 1992; Spinelli & Lupker, 2020; Stroop, 1935) was used to assess inhibition. In this task, names of colors are printed on the screen and the participant is asked to respond to the colors of the printed names, but not the names. This produces congruent trials and incongruent trials. In congruent trials, the names and colors are same, while with incongruent trials, they are different. Sixty trials quasi-randomized were presented which were made up of 30 congruent and 30 incongruent trials. In the affective version of the Stroop task (Chechko et al., 2009; Etkin et al., 2006; Rey et al., 2014), emotional facial expressions depicting *anger*, *sad* and *happy* were used with the corresponding words translucently written across each face. These emotional expressions were specifically chosen based on the notion that they are easily identifiable and distinguishable. Congruent trials would involve when the emotional expression and the emotion written across the face are same. If they are different, that makes it an incongruent trial. Like the non-affective Stroop task, 60 trials were presented in the affective Stroop task made up of 10 congruent trials and 10 incongruent trials for each emotional expression. Accuracy rates and RT were recorded for each trial.

2.2.2 ER tasks and measures

ER task

The pictures for the ER task were selected from the International Affective Picture System database (IAPS; Lang et al., 1997). Specifically, 72 unpleasant and neutral pictures were used for the task. The 48 unpleasant pictures (mean valence = 1.87, mean arousal = 6.31) depicted *mutilated bodies*, *corpses*, and *violence*, whereas the 24 neutral pictures (mean valence = 5.22, mean arousal = 2.82) contained images of *household objects*, *animals*, and *shapes*.

The ER task originally suggested by Gross (1998) and is widely used in contemporary studies of ER (Beauchamp et al., 2016; Hendricks & Buchanan, 2016; Liang et al., 2017; McRae et al., 2012). The ER task was adapted to assess the effectiveness of cognitive reappraisal and expressive suppression strategies. Neutral and unpleasant pictures were presented on the computer screen for 6 seconds followed by 12 to 18 seconds rest period with an instruction to 'look', 'reappraise' or 'suppress'. The rating screen appeared next, where participants were asked to respond between 1 to 9, how negative they felt after viewing the picture. 'To look' meant that the participant should just view the picture and let their feelings flow naturally. 'To suppress' instruction meant that the participant should hide their feelings after seeing the picture. 'To reappraise' required that, the participant should reinterpret the scene in order to have less emotional impact. Prior to the start of the task, participants completed a practice session where each of the instructions were presented in detail on the computer screen as adapted from a previous study (Richards & Gross, 2000). There were 72 quasi-randomized trials divided into 4 blocks of 18 trials. Two blocks had neutral and reappraise instruction while the other 2 blocks had neutral and suppress instructions. The blocks were also quasi-randomized for each participant. Not more than three pictures of the same valence type and instruction (e.g., unpleasant or neutral) were presented in a row to avoid a sequential effect (Kosonogov, 2020).

Emotion regulation questionnaire

To assess the frequency of cognitive reappraisal and expressive suppression, the Russian adaptation of the Gross Emotion Regulation Questionnaire (ERQ: Gross & John, 2003; Pankratova & Kornienko, 2017) was used. This is a 10-item Likert-scale format where participants respond to each statement relating to the ways by which they use the two strategies. Cognitive reappraisal subscale had 6 items (e.g., ‘I control my emotions by changing the way I think about the situation I’m in’) while expressive suppression subscale had 4 items (e.g., ‘I control my emotions by not expressing them’). Participants rated the degree to which they agree or disagree with each statement from 1 to 7.

2.3 Procedure

The PsychoPy software (Peirce et al., 2019) was used to run the experiment. All tasks were carried out on a computer screen with the keyboard and mouse used for the responses. The participants first completed the EF tasks beginning with the n-back, letter-number and the Stroop tasks. In each task, a non-affective version was administered first, followed by an affective version. Afterwards, a participant proceeded to the ER tasks. Electrodes were placed on the *corrugator supercilii* and *zygomaticus major* regions to measure EMG. SCR and HR were also recorded. The participants then proceeded to the ER task with physiological registration. In the ER task, two blocks had instructions to look and to reappraise whiles the other two blocks had to look and suppress instructions. The order of presentation of these blocks were quasi-randomized. At the end participants completed the Gross ERQ. This is further illustrated in Figure 1. The experiment lasted for an hour.

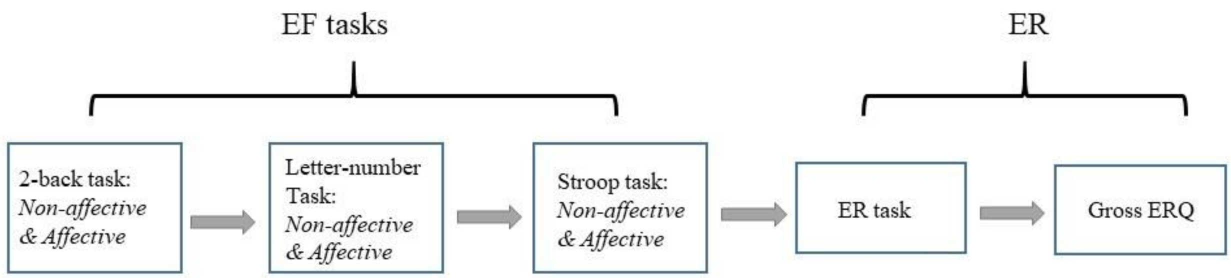

Figure 1. Procedure of the experiment

2.4 Data processing

The mean RTs of correct responses in all the EF tasks were calculated. To obtain the index of updating, mean accuracy score was obtained for each participant, after which the mean RT of correct responses were computed and used as the updating measure. For shifting, the difference between mean RT of same trials and mean RT of different trials was calculated and used as the index of shifting task. The cost of inhibition was obtained by subtracting the mean RT of incongruent trials from the mean RT of congruent trials. For both the shifting and inhibition costs, the greater the indices, the better are shifting and inhibition functions respectively.

The physiological signals during the ER task were collected, amplified, and filtered using the ActiChamp data acquisition system (Brain Products, Germany). The signals were continuously recorded at 1000 Hz. The zygomaticus major and the corrugator supercilii (EMG) activity was attained from the right side of the face using the bipolar placement of 4-mm Ag/AgCI surface electrodes (Fridlund & Cacioppo, 1986). After amplifying the new raw EMG signal, frequencies less than 10 Hz and greater than 350 Hz were filtered out. Having rectified the signal at full-wave, it was integrated with a constant time of 500 ms. In each picture, the activity of zygomaticus major and corrugator supercilii were deduced by subtracting the activity in the first second before picture onset from the mean activity occurring during the 6 seconds of picture presentation.

For skin conductance, the responses were collected through bipolar placement of Ag/AgCI surface electrodes on left hand, the second and fourth finger. The fingers were non-dominant for all participants. The signal in its raw form was calibrated to detect movement within the microSiemens range of 0-100. The SCRs were obtained as the magnitude peaks occurring from 0.9 seconds to 4 seconds after the start of picture presentation (Venables & Christie, 1980). The resulting data was transformed (log10[SCR+1]) to correct the skewed data distribution (Boucsein, 2012).

The amplitude of blood volume was recorded using photoplethysmograph. This was done on the distal phalange of the middle finger on the left hand (also, non-dominant for all participants). HR, that is beats per minute, was computed from the peak of the amplitudes, and the deceleration calculated as the difference between HR at each second of the picture presentation and that of the baseline (a second prior to stimulus onset).

To obtain the outcome variable for cognitive reappraisal and expressive suppression via the various measures (i.e., self-report, zygomaticus major EMG, corrugator supercilii EMG, SCR and HR deceleration), the mean value of each variable during reappraisal and suppression was subtracted from the mean value during look condition. Thus, a greater value signified a better regulation outcome. The outcome variables for the frequency of cognitive reappraisal and expressive suppression were computed by calculating the mean of each subscale of the ER questionnaire. Due to participant error and incomplete data, the final sample for each of the EF and ER measures includes the following: n-back task 78, Stroop task 79, Letter-number task 78, corrugator supercilii EMG 78, zygomaticus EMG 78, SCR 78, HR deceleration 78, ratings 79, ER questionnaire 79.

2.5 Data analysis

A Kolmogorov-Smirnov test for normality was conducted on all the final variable outcomes. The results showed that most of the variables were not normally distributed which suggests that non-parametric methods be applied for the statistical analysis. To test the effectiveness of the ER strategies on each outcome measure, a Friedman analysis was carried out on the ER dependent samples with 4 conditions (looking at neutral pictures, looking at negative pictures, suppress, and reappraise). The post-hoc analysis (on the 4 conditions) was conducted using mean rank difference as recommended for non-parametric analyses (Conover, 1998). Finally, to test the relationship between EF and ER, we ran the Spearman rank correlation. The multiple correlations were corrected using the false discovery rate (Benjamini & Hochberg, 1995).

Results

3.1 Self-report and psychophysiological responses during the ER task

The summary of mean, Friedman's analysis results and the post-hoc analysis for cognitive reappraisal and expressive suppression in all conditions are shown in Table 1. There was a significant main effect of experimental conditions on all measurement outcomes. Whiles cognitive reappraisal was effective at reducing negative emotion in the ER measures except in HR deceleration, expressive suppression was effective in reducing negative emotion in all the ER measures. There were no significant differences between cognitive reappraisal and expressive suppressions in both the self-report and psychophysiological responses as observed in Table 1. Overall, the ER strategies were effective at reducing the negative emotion experienced during the presentation of the unpleasant pictures.

Table 1. Summary of means, Friedman's analysis and post-hoc comparisons of conditions during the ER task.

ER measures	χ^2 (df=3)	No-regulation: Look neut. (*SE*)	No-regulation: Look unpl. (*SE*)	Regulation: suppress unpl. (*SE*)	Regulation: reappraise unpl. (*SE*)
Self-report, 1-9	181.19***	1.20 (.03) [a,b,c]	6.04 (.21) [a,d,e]	5.46 (.21) [b,d]	5.01 (.19) [c,e]
zygomaticus EMG, μV	27.02***	.20 (.05) [a,b]	.16 (.04) [c,d]	.06 (.06) [a,c]	.15 (.10) [b,d]
corrugator EMG, μV	59.12***	-.06 (.05) [a,d,e]	.63 (.15) [a,b,c]	.13 (.07) [b,e]	.18 (.07) [c,d]
SCR, μSiemens	14.84**	.104 (.010) [a]	.163 (.002) [a,b,c]	.116 (.001) [b]	.117 (.001) [c]
HR dec., bpm	16.57***	-3.81 (.24) [a,c]	-4.26 (.27) [b]	-4.94 (.28) [a,b]	-4.39 (.28) [c]

Note: Means in each row with same superscripts differ at p<.05 after correction using false discovery rate method (Benjamini-Hochberg, 1995), ** = p < .01, *** = p < .001, neut = neutral, unpl = unpleasant, dec. = deceleration, bpm= beats per minutes, SE = standard error of mean

3.2 The comparison of affective and non-affective EF tasks

The summary of means and standard errors of mean for the three EF tasks are shown in Table 2. The comparison of the non-affective and affective EF tasks showed a significant mean difference between non-affective and affective updating task using both accuracy rates (t (77) = 2.59, p = .01) and RT (t (77) = 9.31, p < .001). While the accuracy rates for affective updating (M = .68, SD = .16) was higher than that of non-affective updating (M = .64, SD = .17), RT of non-affective updating (M = 1.15, SD = .19) was smaller than that of affective updating (M = 1.32, SD = .19). There was no difference between non-affective and affective inhibition costs (t (78) = .53, p = .56), and shifting costs (t (77) = 1.98, p = .051). In summary, this suggests that affective updating was processed with much efficiency than non-affective updating. The difference between affective and non-affective shifting and inhibition were not statistically significant. This implied that affective content did not matter in the performances of the shifting and inhibition tasks.

Table 2: Summary of descriptive statistics for the EF measures

Executive functions	Non-affective (*SE*)	Affective (*SE*)
Updating ACC	.64 (.02)	.69 (.02)
Updating RT (s)	1.15 (.02)	1.32 (.02)
Shifting: Congruent RT	.82 (.02)	.90 (.02)
Shifting: Incongruent RT	1.24 (.03)	1.38 (.03)
Shifting cost	-.43 (.02)	-.48 (.02)
Inhibition: Congruent RT	.73 (.02)	.97 (.02)
Inhibition: Incongruent RT	.92 (.04)	1.15 (.03)
Inhibition cost	-.19 (.03)	-.18 (.03)

Note s=seconds, *SE* = standard error of mean

3.3 The relationship between executive functions and emotion regulation

The summary of correlations between EF and cognitive reappraisal is shown in Table 3 while that of EF and expressive suppression is presented in Table 4. On the relationship between EF and psychophysiological responses during ER, we found that faster updating of non-affective stimuli was associated with larger change in HR deceleration when asked to reappraise (r_s (77) = -.249, p = .029). This meant that better updating ability produced significant change in HR deceleration when participants applied the reappraisal strategy of ER. Larger inhibition cost over non-affective stimuli resulted in greater reduction of zygomaticus EMG when asked to suppress (r_s (77) = .254, p = .026). This implied that performance in the inhibition task was positively associated with zygomaticus major when participants applied the suppression strategy of ER.

On the relationship between EF and self-reported frequency of ER strategies (measured by ERQ), the results showed a significant positive correlation between cost of inhibition over non-affective stimuli and suppression on the one hand (r_s (79) = .246, p = .029) and cost of inhibition over affective stimuli and suppression on the other hand (r_s (79) = .264, p = .018). This is shown in both Tables 3 and 4. This meant that the ability to inhibit over non-affective or affective stimuli was associated with higher frequency of the use of the suppression strategy of ER.

Table 3. Spearman correlation coefficients between EF and measures of cognitive reappraisal

EF	SCR	Zygomaticus EMG	Corrugator EMG	HR dec.	Δ Self-reported mood	ERQ: REAP
Updating RT	.11	.01	-.14	-.25*	-.09	-.06
Affective updating RT	.09	.02	-.11	-.16	-.09	.03
Shifting	-.18	-.05	.01	-.02	-.01	-.08
Affective shifting	-.15	.05	-.09	-.10	.08	.14
Inhibition	-.10	-.01	.14	.05	.06	.14
Affective inhibition	-.07	.03	.01	.16	-.15	.09

Note: RT= response time, ERQ= emotion regulation questionnaire, REAP= reappraisal *, p<.05 after correction using the false discovery rate (Benjamini-Hochberg, 1995).

Table 4. Spearman correlation coefficients between EF and measures of expressive suppression

EF	SCR	Zygomaticus EMG	Corrugator EMG	HR dec.	Δ Self-reported mood	ERQ: SUPP
Updating RT	-.04	-.15	-.17	-.08	-.18	-.02
Affective updating RT	.08	-.16	-.11	.03	-.06	-.03
Shifting	-.11	.14	-.04	-.04	.14	.08
Affective shifting	-.06	.20	.01	-.11	.17	.10
Inhibition	-.14	.25*	-.00	-.13	.19	.25*
Affective inhibition	-.16	.21	-.19	-.11	.13	.26*

Note: RT= response time, ERQ= emotion regulation questionnaire, SUPP=suppression *, p<.05 after correction using the false discovery rate (Benjamini-Hochberg, 1995).

In summary, we found that individuals with higher updating ability demonstrated higher change in HR deceleration when asked to reappraise. Inhibition of non-affective stimuli was positively associated with greater reduction of zygomaticus major using suppression strategy of ER. The ability to inhibit prepotent responses was associated with more frequent use of the suppression strategy of ER. We failed to find an association between updating and ER strategies measured with SCR, zygomaticus major and corrugator supercilii EMG and self-report. Shifting was associated with neither cognitive reappraisal nor expressive suppression (as measured with self-reports and psychophysiological responding).

Discussion

The present study investigated the role of EF in the ability to regulate emotions. Although previous research advanced into this question, there are some gaps still unanswered. To this end, three core EF, namely updating, shifting and inhibition were assessed using the n-back, letter-number and Stroop tasks respectively. Also, participants performed an ER task providing the behavioral and psychophysiological indices of cognitive reappraisal and expressive suppressions. The Gross ERQ was also used to measure the frequency of ER strategies.

The results suggest that updating is related to cognitive reappraisal measured with HR deceleration. That is people, who updated better, also experienced larger HR deceleration when using cognitive reappraisal strategy of ER. This finding is novel and extends the growing body of research which found that updating is positively related to cognitive reappraisal (Hendricks & Buchanan, 2016; Mohammed & Lyusin, 2020; Pe et al., 2008; Sperduti et al., 2017). Whereas the previous studies largely used self-reports and questionnaires in the assessment of ER strategies, the present study extended the association by showing that it also exists in HR deceleration during ER activity. Moreover, the present study assessed EF with the use of affective and non-affective stimuli and found this association with non-affective updating. Curiously, updating did not relate to cognitive reappraisal or expressive suppression using the self-reports, frequency of ER strategies and the EMG and SCR as reported in other studies (Gyurak et al., 2012; Hoorelbeke et al., 2016). Regulating an emotion through cognitive reappraisal strategy would involve re-evaluating the existing emotional stimuli to make them less impactful, a skill which would be supported by an efficient updating function. There is converging evidence suggesting that HR decelerates greater in relation to an unpleasant emotional encounter (Bradley et al., 2001; Sánchez-Navarro et al., 2006), and that the deceleration increases when an individual attempts to suppress the emotion. HR deceleration may be considered a reflection of efforts rather than experience of negative emotions as observed during ER. The present results showed that, not only the HR deceleration becomes larger during reappraisal, but that efficient updating leads to greater change in HR deceleration.

We found that the cost of inhibition was related to the frequency of the use of suppression as predicted. That is people, who performed better inhibition tasks, also reported higher frequency of the use of suppression strategy in daily life. To suppress any form of emotional expression (i.e., experiential, behavioral or physiological responses) would involve the ability to inhibit prepotent responses, a process which characterizes inhibition function. Thus, individuals who are better at inhibition tasks do experience higher emotional suppression as well. This finding extends previous research that found an association between inhibition and suppression in general (Von Hippel & Gonsalkorale, 2005). Whereas the present result demonstrated the positive correlation between inhibition and frequency of suppression, Von Hippel & Gonsalkorale (2005) found the positive association between inhibition and suppression ability. Some other studies failed to find an association between inhibition and suppression (Aker et al., 2014; Hendricks & Buchanan, 2016). It is worth to note that these two studies used a different method to measure inhibition, a stop signal task whereas we used the classical and the affective versions of the Stroop task. Aker et al. (2014) measured suppression with the ERQ (as we did); Hendricks & Buchanan (2016) measured suppression using the ER task. The differences in the findings could be as a result of the different paradigms used in the studies.

Contrary to our expectation, the ability to shift between tasks was associated neither with cognitive reappraisal nor expressive suppression strategies of ER. The present finding is consistent with previous results reported in other studies (Malooly et al., 2013; Sperduti et al., 2017). However, while some studies reported positive association between shifting and ER (Hendricks & Buchanan, 2016; Liang et al., 2017), others found negative relationship between shifting and ER (McRae et al., 2012). It is important to note that older adults were used in the previous study (Liang et al., 2017) as compared to the younger adult used in the present study. Majority of the studies suggests no association between shifting and ER, despite the diverse tasks used in the assessment of shifting (for a complete review, see Pruessner et al., 2020). One possible explanation is that shifting ability is a broad concept which represents other complex cognitive processes.

On the possible role of affective content of the EF tasks in ER strategies, the pattern of results obtained showed that the relationship between EF and ER is not impacted by the affective content of the tasks. Although previous studies (e.g., Hendricks & Buchanan, 2016; Mohammed & Lyusin, 2020) showed similar trend, they did not directly test this assumption by using both versions of the task in their experiments. According to the *dual competition framework* (Pessoa, 2009), affective content in EF tasks do have an impact on task performance. However, a recent meta-analytic study suggested that affective content might have little to negligible impact on working memory performance in a healthy population (Schweizer et al., 2019). This could account for the pattern of results obtained in the present study.

The study has some limitations. We recruited largely undergraduate students for the experiment. Hence, the interpretation of the results must be done with caution in terms of the generalization of the present findings. Moreover, due to the nature of the ER task, it is also possible that some participants were just obeying instructions during the picture presentation.

Overall, the present data confirm the idea that a higher level of EF is partially related to the efficient application of ER strategy. Notably, inhibition assessed with non-affective and affective Stroop tasks is related to the higher frequency of the use of expressive suppression. Affective content in EF tasks does not play a substantive role in the relationship between EF and ER strategies.

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