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To Switch or Not to Switch: Individual Differences in Executive Function and Emotion Regulation Flexibility

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Abstract

Emotion regulation (ER) constitutes strategies that modulate the experience and expression of emotions. While past work has predominantly focused on each ER strategy independently, recent research has begun to examine individual-difference factors that are associated with the flexible implementation of ER strategies in line with environmental demands (i.e., ER flexibility). Considering that ER processes generally implicate executive function (EF)—a collection of adaptive, general-purpose control processes—it is plausible that EF could be involved in ER flexibility. Using a latent-variable approach based on a comprehensive battery of EF tasks, the present study investigated how the various aspects of EF (i.e., common EF, working-memory-specific, and shifting-specific factors) are related to the flexible maintenance and switching of ER strategies in response to stimuli that elicit varying levels of emotional intensity. Results indicated that better working-memory-specific ability (i.e., the ability to manipulate and update information within a mental workspace) was associated with greater ER strategy variability and higher frequency of ER strategy switching in high-, relative to low-, intensity contexts. Further, more proficient common EF (i.e., the ability to sustain relevant goals in the face of competing goals and responses) corresponded to greater propensity to maintain ER strategy for contexts with low-, but not high-, negative intensity. The outcomes of this study offer a richer understanding of the cognitive mechanisms underlying ER flexibility.

Keywords: executive function, inhibition, working memory, shifting, emotion regulation flexibility, emotion regulation choice

To Switch or Not to Switch: Individual Differences in Executive Function and Emotion Regulation Flexibility

Emotion regulation (ER) refers to processes that modify how and when emotions are expressed and experienced (Gross, 2008). A widely studied ER strategy is cognitive reappraisal (henceforth *reappraisal*), which refers to the reframing of one or more interpretations of a situation to increase or decrease its emotional impact (Gross, 2008; Gross & John, 2003). Decades of research have documented the benefits of reappraisal on various domains in life, such as interpersonal relations, self-esteem, resilience, subjective well-being, and psychological well-being (Gross & John, 2003; John & Gross, 2004). However, there is an increasing recognition that reappraisal is not necessarily the optimal strategy in every situation, thereby highlighting the importance and adaptiveness of implementing ER strategies that are synchronised with contextual demands (i.e., ER flexibility; Aldao et al., 2015; Ford & Troy, 2019).

While past research has demonstrated that the ability to successfully reappraise emotional experiences is dependent on a collection of adaptive, general-purpose control processes—known as executive function (EF; Schmeichel & Tang, 2014, 2015)—less is known regarding the role of EF in the flexible use of ER strategies. Given that EF has been hypothesised to be involved in ER flexibility (Pruessner et al., 2020; Sheppes et al., 2014), the present study sought to investigate how the various EF dimensions (i.e., common EF, working-memory-specific, and shifting-specific factors) would be associated with two aspects of ER flexibility (i.e., maintaining and switching ER strategies).

The Unity/Diversity Framework of Executive Function

A popular conceptualisation of EF is the unity/diversity framework (Miyake et al., 2000), which details three intercorrelated (i.e., unity), but separable (i.e., diversity), regulatory processes—namely, inhibition, working memory, and shifting—as derived from a confirmatory factor analysis of a battery of nine commonly used EF tasks. Inhibition refers to the suppression of prepotent or automatic response tendencies. Working memory updating (henceforth *working memory*) relates to the manipulation and updating of information within mental workspace, such as the removal and inclusion of irrelevant and relevant information, respectively. Shifting is defined as the flexible switching back and forth between multiple mental sets and tasks. In a recent revision of the unity/diversity framework (Friedman & Miyake, 2017), a common EF factor—which refers to the ability to activate, maintain, and monitor task-relevant information and goals—has been proposed to represent the intercorrelations between all three EF facets. In this nested-factor model, after the common EF factor (i.e., unity) has been extracted, working-memory-specific and shifting-specific factors (i.e., diversity) were formed from the remaining variance unique to working memory and shifting tasks, respectively. Notably, there was no more unique variance among inhibition tasks to establish an inhibition-specific factor. Given that inhibition tasks predominantly engage the common EF ability to sustain goal-relevant information (e.g., Chatham et al., 2012; Hampshire et al., 2010), the inclusion of the common EF factor obviates the need for an inhibition-specific factor.

Extant empirical evidence corroborates the nested-factor EF model. For instance, neuroimaging studies show that the specific dimensions of EF are associated with different regions of the prefrontal cortex. Notably, common EF is subserved primarily by the frontoparietal network and the ventromedial prefrontal area, while working-memory-specific and shifting-specific factors are uniquely supported by the dorsolateral and ventrolateral prefrontal regions, respectively (Smolker et al., 2015; Stuss & Alexander, 2007; Tsuchida & Fellows, 2008; Yarkoni & Braver, 2010). Behavioural evidence highlights that the three EFs are divergently related to various outcomes. To illustrate, common EF has been shown to be associated with polysubstance use (Gustavson et al., 2017), self-regulation (Tiego et al., 2020), trait worry (Gustavson et al., 2020), and stereotypic impulses (Ito et al., 2015); the working-memory-specific factor strongly predicted fluid and crystallised intelligence (Friedman et al., 2006); and the shifting-specific factor was uniquely linked to smartphone screen time and checking frequency (Toh et al., 2021). These findings demonstrate that EF comprises a general, shared component (i.e., common EF) as well as unique, distinct components (i.e., working-memory- and shifting-specific factors).

Emotion Regulation

ER strategies can be classified as antecedent-focused, which occur prior to the generation of fully developed emotional responses, or response-focused, which occur after the formation of complete emotional responses (Gross, 2008). Antecedent-focused strategies comprise situation selection (i.e., choosing situations based on the emotions that these situations would elicit), situation modification (i.e., altering aspects of situations), distraction (i.e., shifting attention away from emotional aspects of the situation), reappraisal (i.e., revising the meaning of the situation), whereas response-focused strategies include expressive suppression (i.e., inhibiting behavioural expressions of emotions). While past research has predominantly investigated the psychosocial correlates of discrete ER strategies, there is a growing interest in the ability to implement situationally appropriate ER strategies in accordance to changing environmental demands and personal goals (i.e., ER flexibility; Bonanno & Burton, 2013).

An emerging body of evidence has provided support for the salubrious effects of ER flexibility on psychological health. For instance, studies that investigate the use of ER strategy in daily life (assessed using experience sampling or daily dairy methods) found that higher between-strategy variability and within-strategy variability (for reappraisal and distraction) are associated with fewer depressive symptoms and lower levels and persistence of negative affect (Blanke et al., 2020; Wang et al., 2020). Likewise, the protective functions of adaptive ER strategies (e.g., reappraisal, acceptance) against psychopathology (i.e., depression, anxiety, and alcohol abuse) are most pronounced among individuals with richer repertoires of ER strategies (Aldao & Nolen-Hoeksema, 2012). Converging evidence from experimental studies highlights that greater flexibility in enhancing and suppressing emotional expressions to emotion-eliciting pictures in accord with experimental instructions predicted better self-rated and peer-rated adjustment (i.e., lower distress) and lower cumulative life stress among college students (Bonanno et al., 2004; Westphal et al., 2010).

An important motivation for research in ER flexibility is the idea that not every ER strategy is adaptive across all situations. To illustrate, while reappraisal has been shown to be beneficial in various psychosocial domains, recent empirical evidence has demonstrated that the adaptiveness of reappraisal is contingent on contextual factors (Ford & Troy, 2019). For instance, in uncontrollable stressful situations, reappraisal may be an effective strategy in managing one’s emotions; conversely, in situations where the stressors are controllable, changing the situation (i.e., problem-focused coping), rather than one’s emotions, may be more ideal. Corroborating this idea, Troy et al. (2010) showed that reappraisal ability is negatively and positively associated with depressive symptoms for participants facing situations involving uncontrollable and controllable stressors, respectively. Relatedly, Perez and Soto (2011) found that among individuals experiencing high racial oppression, higher frequency of reappraisal was associated with greater depressive symptoms, whereas higher reappraisal frequency was linked to fewer depressive symptoms for those facing low racial oppression.

More causal evidence comes from laboratory-based experiments that directly manipulated contextual factors. For instance, when facing highly intense emotional situations, it may be too cognitively taxing to employ reappraisal, which requires engaging with—and transforming the meaning of—emotion-eliciting stimuli. Specifically, in a study by Sheppes et al. (2011) that used a variety of emotion-eliciting pictures, participants preferred reappraisal for low-intensity negative pictures, while distraction—a cognitive disengagement strategy—is preferred under high-intensity negative pictures. Using the same emotion-regulation choice paradigm, Levy-Gigi et al. (2016) found that traumatic exposure was positively correlated with posttraumatic stress disorder symptoms among firefighters who more frequently selected reappraisal, instead of distraction, for high-intensity negative pictures, thereby suggesting that lower ER variability may be a risk factor for psychopathology. Another study by Birk and Bonanno (2016) showed that individuals with greater responsiveness to internal feedback (i.e., corrugator activity, heart rate) predicted the tendency to switch from a suboptimal (i.e., reappraisal) to an optimal (i.e., distraction) strategy in response to high-intensity negative pictures. Moreover, for individuals with higher levels of responsiveness to internal feedback, more frequent reappraisal-to-distraction switches was concomitant with higher life satisfaction. Together, the findings from past studies highlight that the adaptiveness of reappraisal is contingent on contextual and individual-difference factors.

Executive Function and Emotion Regulation

Current theories in affective sciences highlight that ER success relies on cognitive resources—most prominently, EF (Schmeichel & Tang, 2014, 2015). For instance, the ability to reappraise emotional experiences requires the manipulation of situational interpretations in one's mind and the controlled retrieval of suitable appraisals from long-term memory (working memory); suppression of undesired appraisals in favour of desired interpretations (inhibition); and switching from goal-incongruent to goal-congruent narratives through the reconfiguration of extant interpretations and resisting proactive interference from initial appraisals (shifting).

Findings from past studies have substantiated the link between EF and reappraisal. For instance, neuroimaging studies highlight that the ability to reappraise emotional material (e.g., reinterpreting negative aspects of stimuli neutrally or positively) is linked to heightened activity in EF-related regions (e.g., ventromedial prefrontal cortex) and attenuated activity in regions responsible for emotional responding (e.g., amygdala; Banks et al., 2007; Buhle et al., 2014; Goldin et al., 2008; Ochsner & Gross, 2005). Findings from behavioural studies using laboratory-based EF and reappraisal tasks substantiate the EF-reappraisal link. To illustrate, performance on working memory measures (e.g., operation-span and keep-track tasks) was positively associated with the ability to reappraise negatively and positively valenced stimuli (Hendricks & Buchanan, 2016; McRae et al., 2012; Schmeichel et al., 2008). Further, individuals with frontal-lobe impairments exhibited greater difficulties on both inhibition and reappraisal tasks as compared to healthy controls (Salas et al., 2014; Tabibnia et al., 2011). Moreover, proficient shifting between different task sets corresponded with the ability to adopt a detached, objective perspective when viewing evocative film clips and pictures (Liang et al., 2017; Malooly et al., 2013). Recent findings emphasize the role of common EF in reappraisal processes. Notably, reappraisal ability was not related to the unique aspects of EF (i.e., working-memory-specific and shifting-specific factors); rather, it was the common EF ability to manage task-relevant goals that predicted reappraisal ability, thereby indicating that reappraisal may be driven by the common EF component instead of processes unique to working memory and shifting (Toh, 2019; Toh & Yang, 2021).

Although past research has focused on the relations of EF with discrete ER strategies (e.g., reappraisal), very few studies have examined the interplay between EF and ER flexibility. Among younger adults, Eldesouky and English (2018) found that higher overall performance on inhibition and working-memory tasks (i.e., verbal fluency, Stroop, and Attention Network tasks) predicted lower variability in the self-reported daily use of various ER strategies (i.e., situation selection, situation modification, distraction, positive reappraisal, detached reappraisal, expressive suppression). In a study by Scheibe et al. (2015), younger (19 to 28 years) and older (65 to 75 years) adults completed an inhibition measure (i.e., flanker task) as well as a laboratory-based ER choice task where they were shown emotion-eliciting pictures, with differing intensity levels, and had to select either reappraisal or distraction. Results indicated that older adults preferred distraction over reappraisal across both low-intensity and high-intensity pictures, and that both younger and older adults with less proficient inhibition more frequently opted for distraction over reappraisal. These findings are consistent, in part, with the Selection, Optimization, and Compensation with Emotion Regulation theory (SOC-ER; Opitz et al., 2012; Urry & Gross, 2010), which posits that individuals with diminished cognitive resources would compensate by choosing ER strategies other than reappraisal that are less cognitively demanding (e.g., distraction, situation selection). In contrast, given that reappraisal is a cognitively taxing but effective ER strategy, individuals with better EF may be able to enact reappraisal with greater success and may prefer to rely on reappraisal instead of other ER strategies.

Limitations of Past Research

Several shortcomings of the limited evidence on EF and ER flexibility hinder definitive conclusions. The first issue concerns the use of single-task EF measures (Scheibe et al., 2015), which is susceptible to the task-impurity problem. Notably, EF tasks typically assess both EF and non-EF processes. To illustrate, the colour-flanker task, which requires participants to identify the colour of the central target that is flanked by distractors of different colours (e.g., a central red square surrounded by blue squares), taps the EF ability of inhibiting visual distractors in addition to the non-EF ability of colour processing. Such non-EF variance may result in spurious correlations or mask true associations between EF with ER processes (Draheim et al., 2016). Indeed, past work has shown that findings from a single EF measure do not generalise to other related tasks that are supposed to tap the same EF dimension (Gustavson et al., 2020; Toh, 2019; Toh & Yang, 2021). Accordingly, more appropriate statistical techniques are needed to minimise the task-impurity problem.

A second limitation involves the independent and limited assessment of EF dimensions (Eldesouky & English, 2018; Scheibe et al., 2015). Notably, considering that each EF facet comprises shared (i.e., common EF) and unique (i.e., working-memory-specific and shifting-specific factors) components (Friedman & Miyake, 2017), inadequate assessments of EF preclude a thorough understanding of the contributions of the various EF components to ER flexibility. For instance, working-memory tasks, which typically require participants to encode and manipulate to-be-remembered items (e.g., reproducing items in a reversed order), recruit the working-memory ability to reconfigure materials within a mental workspace and the common EF ability to sustain relevant task goals without being unduly interrupted by irrelevant distractions. Further, the different EF components are not similarly predictive of behavioural outcomes (e.g., Friedman et al., 2006; Friedman & Miyake, 2017). For instance, common EF, working-memory-specific, and shifting-specific factors sometimes show opposing relations with other constructs (e.g., self-regulation, frequency of smartphone checking; Friedman et al., 2011; Toh et al., 2021). Therefore, a comprehensive examination of EF is warranted to elucidate whether the shared and unique components would be similarly or differentially implicated in ER flexibility.

A third limitation relates to the lack of evidence on how EF are recruited in specific processes that are integral to the flexible implementation of ER strategies, given that past research has relied on general indices of ER flexibility over extended period of time (e.g., total number of strategies used per day, variability in strategy use across days; Eldesouky & English, 2018). Notably, the cognitive control framework of ER flexibility advances that the maintenance of an existing ER strategy versus the switching of ER strategies entail various EF dimensions (Pruessner et al., 2020). Strategy maintenance encompasses the continual conversion of regulatory goals into context-specific tactics without being disrupted by internal and external task-irrelevant distractions, thereby ensuring that one's emotions continues to be regulated until the desired emotional state has been achieved. In this regard, strategy maintenance involves sustaining relevant strategy-specific information while preventing distractors and response tendencies from interfering with strategy maintenance (common EF); and the ability to track and retain relevant regulatory information within mental workspace (working memory; Pruessner et al., 2020). Conversely, strategy switching, which refers to the capacity to discontinue a present ER strategy and switch to a more appropriate strategy, entails all three EF facets (Pruessner et al., 2020). Specifically, ER strategy switching involves stopping current ER processes to switch to a different ER strategy or other goals (shifting); suppressing or resolving the impulse to continue with a previous ER strategy (inhibition); and updating of working-memory contents by replacing outdated material with more relevant information regarding ER processes (working memory). Hence, the various EF components may play distinct roles in ER strategy maintenance and switching.

The Present Study

Based on the issues highlighted, the goals of the current study are as follows. First, to tackle the task-impurity problem in EF measures, we employed a latent-variable approach based on multiple tasks to measure each EF dimension. Notably, the latent-variable approach provides a cleaner estimation of EF facets by accounting for measurement errors and task-specific, non-EF processes (Friedman & Miyake, 2017; Miyake et al., 2000), thereby affording greater precision in the assessment of the relations between EF and ER flexibility. Second, given the unity and diversity of EF (Friedman & Miyake, 2017), we used nested-factor modelling to examine how the shared (i.e., common EF) and unique (i.e., working-memory-specific, and shifting-specific factors) EF components would be related to ER flexibility.

Third, to empirically test the links between EF and ER strategy maintenance and switching, we adopted the experimental paradigm from Birk and Bonanno (2016). Specifically, participants were instructed to first reappraise emotion-eliciting pictures, which varied in intensity levels, and then make a choice to continue using reappraisal or to switch to distraction, thereby allowing for the examination of how strategy maintenance and switching would be related to EF across different emotional contexts. Considering that past research has shown that reappraisal and distraction are preferred in low- and high-intensity situations, respectively (e.g., Scheibe et al., 2015; Sheppes et al., 2011), we anticipated higher levels of strategy switching (i.e., from reappraisal to distraction) for high-intensity contexts and lower levels of strategy switching (i.e., maintaining reappraisal) for low-intensity contexts. Specifically, reappraisal is favoured in low-intensity situations owing to the attenuation of emotional experiences and the facilitation of long-term affective adaptation, whereas distraction is preferred in high-intensity situations due to the hindering of affective information at an early stage before it gains momentum (Sheppes et al., 2014).

Drawing from the cognitive control framework of ER flexibility (Pruessner et al., 2020), the following hypotheses were tested. In low-intensity environments that favour strategy maintenance of reappraisal, better common EF and working-memory-specific abilities would be concomitant with higher frequency of strategy maintenance. In high-intensity environments that are conducive to reappraisal-to-distraction strategy switching, more proficient common EF, working-memory-specific, and shifting-specific abilities would be associated with greater frequency of strategy switching (relative to switching frequency at low-intensity situations). As an additional index of ER flexibility, we explored the potential link between EF and variability in ER strategy switching (e.g., Bonanno & Burton, 2013; Eldesouky & English, 2018). Specifically, greater variability in strategy switching variability, which measures dispersion or fluctuation in ER strategy maintenance and switching across situational demands, denotes a more balanced pattern of ER strategy use. Finally, to ensure that the associations between EF and ER flexibility are not attributed to third-variable effects, we controlled for potential covariates (i.e., gender, fluid intelligence, depressive symptoms, and reappraisal ability) that have been documented to influence EF or ER processes (Birk & Bonanno, 2016; Ehring et al., 2010; Friedman et al., 2006; McRae et al., 2008; Toh & Yang, 2021; Urbanek et al., 2009).

Method

Participants

One hundred and eighty-four undergraduate students participated in the study for course credits or monetary reward (S$50). The sample size is consistent with previous research that employed the latent-variable approach, based on multiple tasks, to measure EF dimensions (e.g., Miyake et al., 2000; Gustavson et al., 2020). Further, Monte Carlo simulations (1,000 iterations) revealed that for a structural equation model with three latent variables and nine manifest variables (see Results), a minimum sample size of 150 is required to detect a medium effect size of .30, as observed in previous studies that have used structural equation modelling to investigate the link between EF and ER processes (e.g., Toh & Yang, 2021). Descriptive statistics for all variables of interest and zero-order correlations are shown in Appendix A.

Materials

Inhibition

Three inhibition tasks assessed the active suppression of prepotent or automatic responses (Friedman & Miyake, 2017).

Antisaccade. Adapted from Unsworth and McMillan (2014), participants had to ignore a flashing distractor on one side of the screen in order to detect a target (i.e., *B*, *P*, or *R*) that was briefly shown on the other side of the screen. Each trial began with the presentation of a fixation point in the centre of the screen for a variable period of time (200 ms to 2,200 ms). Next, the distractor (100 ms), in the form of an equal sign, was flashed either to the left or right of the fixation point (11.33° of visual angle). This was followed by a blank screen (50 ms) and the second appearance of the distractor (100 ms) to intensify the attentional capture of the distractor.

After another presentation of a blank screen (50 ms), the target (150 ms) appeared on the opposite side from where the previously shown distractor (11.33° relative to the fixation point). Finally, the target was masked by the letter *H* (50 ms) and the number *8* until a response was provided. There were 24 practice trials and 72 experiment trials. Higher proportion of correct responses denoted better performance.

Go/no-go. Adapted from McVay and Kane (2009), participants responded to non-*X* letters (i.e., go trials), by pressing the spacebar on the keyboard, except for the target *X* letter (i.e., no-go trials). In each trial, a letter stimulus was first shown (400 ms), followed by a blank screen (900 ms) or until a response was given. There were 267 go trials and 33 no-go trials. The infrequent presentation of the *X* letter (11% of the time) implicates the inhibition of the impulse to press the spacebar. Higher proportion of correct responses on the no-go trials represented more proficient performance.

Stroop. In this variant of the classic Stroop task (Altamirano et al., 2010), participants discerned—by pressing the *R* (red), *Y* (yellow), *G* (green), or *B* (blue) key—the colour of a target word rather than reading the word (e.g., the word “red” printed in blue ink). Each trial began with a fixation point (750 ms) followed by the target word, which remained on the screen for 2,000 ms or until a response was provided. There were two types of randomly presented trials: (a) 144 congruent trials where the target word matched the colour it was printed in (e.g., the word “blue” printed in blue ink), and (b) 48 incongruent trials where the target word conflicted with the colour in which it was printed in (e.g., the word “green” printed in yellow ink). Participants completed 10 practice trials before commencing with 192 experiment trials. Following Altamirano et al. (2010), higher proportion of correct responses on the incongruent trials indicated better performance.

Working Memory

Three working-memory tasks measured the ability to manipulate and update information within a mental workspace (Friedman & Miyake, 2017).

Keep Track. Adapted from Yntema (1963), participants were presented with words that belonged to different categories (i.e., animals, distances, relatives, colours, and countries) and had to recall the last item from each category. In each trial, 15 items were shown in the middle of the screen one at a time for 1,500 ms each and the target categories were displayed at the bottom of the screen. There were 12 trials and the maximum number of to-be-recalled items in each trial (set size) randomly ranged from 2 to 4. Higher proportion of correctly recalled letters signified better performance.

Two back. In this version of the *n*-back task (Jaeggi et al., 2010), participants saw a sequentially presented string of numbers and had to indicate, by pressing the spacebar, if the current number matched the number shown two trials before. In each trial, the to-be-remembered number was shown for 1,500 ms and the interval between each number was 1,000 ms. There were 4 blocks with 17 letters each. Higher proportion of accurate responses represented better performance.

Corsi block tapping. A computerised backward span version of the Corsi block-tapping task was implemented (Kessels et al., 2008). In each trial, an array of nine cubes, which lit up one at a time (1,000 ms) in a random order, was presented. Participants had to tap on the cubes in the reversed order in which they were lit up. There were two trials per set size—which ranged from 2 to 8, presented in an incremental order—and the task was terminated once both trials of a set size were incorrect. Following Kessels et al. (2008), a product score was computed by multiplying the highest set size achieved with the total number of correct responses; higher values denoted better performance.

Shifting

Three shifting tasks tapped the ability to switch back and forth between multiple mental sets, based on the task-switching paradigm (Monsell, 2003).

Colour shape. Depending on a given cue, participants sorted a target (i.e., red triangle or green circle) according to either the colour rule (i.e., red or green) or the shape rule (i.e., triangle or circle) by pressing the *D* (i.e., circle or red) or *K* (i.e., green or triangle) keys. The cues for the colour and shape rules were a colour gradient and a row of black squares, respectively. In each trial, a fixation point (350 ms) and then a blank screen (150 ms) were shown. Next, the cue was presented, followed by the target after a delay (250 ms). Both the cue and target remained on screen until a response was provided. The interval between the response to the next trial was 800 ms, as signified by a blank screen. There were two pure blocks that comprised only colour or shape rules (20 trials each), followed by two mixed blocks (30 trials each) with an equal number of switch trials (e.g., colour rule followed by shape rule) and repeat trials (e.g., two consecutive trials of colour rule). The trial order was randomized, with the maximum number of consecutive repeat trials set at four. The dependent variable was reverse-coded bin scores (see Binning Procedure), where higher values denoted better performance.

Magnitude parity. Based on the cue presented, participants sorted a target (i.e., 2 or 7) according to the magnitude rule (i.e., smaller or greater than five) or the parity rule (i.e., odd or even) by pressing the *D* (i.e., odd number or less than five) or *K* (i.e., even number or more than five) keys. The cues for the magnitude and parity rules were signified by rows of circles of varying sizes and rows of odd- and even-numbered squares, respectively. All other methodological details were similar to the colour-shape task.

Animacy locomotion. Contingent on the presented cue, participants sorted a target (i.e., plane or rabbit) according to the animacy rule (i.e., living or nonliving) or the locomotion rule (i.e., flying or nonflying) by pressing the *D* (i.e., living or flying) or *K* (i.e., nonliving or nonflying) keys. The cues for the animacy and locomotion rules were signified by images of dog paws and roads, respectively. All other methodological details were similar to the colour-shape task.

Emotion Regulation Flexibility

Following Birk and Bonanno (2016), participants were first trained in the ER strategies of reappraisal and distraction, using a standard ER paradigm (McRae et al., 2012), followed by the ER choice task. During the training phase, participants viewed neutral and unpleasant target pictures presented in the centre of the screen and had to employ (a) reappraisal, which includes imagining how the situation would change for the better, or identifying aspects of the situation that are not as bad as they seem (“Reframe”), (b) distraction, which involves reorientating attention from a more negatively valenced target picture to neutral pictures located at the four corners of the screen (“Distract”), or (c) view the pictures naturally (“Look”), depending on the experimental instructions (i.e., “Reframe”, “Distract”, and “Look”) shown at the beginning of each trial. At the end of every trial, participants rated their negative emotions (1 = *not at all*, 7 = *very negative*). There were 15 trials for each condition: look instruction with neutral pictures, look instruction with negative pictures, reframe instruction with negative pictures, and distract instruction with negative pictures.

We conducted two manipulation checks to assess whether the unpleasant pictures elicited negative emotions and whether participants engaged in the ER strategies of reappraisal and distraction. First, participants rated the pictures in the “Look Negative” trials as more negative than those in the “Look Neutral” trials, $t(183) = 46.76$, $p < .001$, indicating that the unpleasant pictures were perceived as more negative than the baseline pictures. Second, the pictures in the “Look Negative” trials were rated more negatively than those in the “Reframe Negative” and “Distract Negative” trials, *t*s > 11.38, *p*s < .001 (adjusted with Bonferroni correction), thereby suggesting that participants actively regulated their emotions during the “Reframe” and “Distract” trials.

Emotion regulation choice. Participants viewed a collection of negatively valenced pictures and had to choose to use either reappraisal or distraction. Participants were instructed to first employ reappraisal for each picture but were given a choice to switch to distraction if they felt that reappraisal was not effective in downregulating negative emotions.

Each trial began with a fixation point (1,000 ms), followed by the instruction “Reframe” (2,000 ms) and a target picture presented in the centre of the screen (5,000 ms). After which, a tone was presented (100 ms), which signalled to the participants that they could switch to distraction (by pressing the spacebar) or continue using reappraisal (not pressing the spacebar). If participants chose to change ER strategies (strategy switching), then the target picture would be surrounded by four neutral images (6,000 ms), which allows for participants to attend to the neutral pictures instead of the central negative picture. If participants chose to continue engaging in reappraisal (strategy maintenance), then the target picture remained on the screen (6,000 ms). Next, participants reported their experienced emotions (*“How negative do you feel?”*; 1 = *not at all*, 7 = *very negative*). The intertrial interval, a screen that read “Relax”, varied between 1,000 ms to 3,000 ms. There were 30 trials and the target pictures, which were selected from the International Affective Picture System (IAPS; Lang et al., 2008), were either low (valence = 3.41; arousal = 5.01) or high (valence = 2.02; arousal = 5.93) negative intensity (15 trials each). The main variables of interest were (a) frequency (i.e., proportion) of ER strategy switching for the low- and high-intensity conditions, and (b) strategy switching variability (expressed in standard deviation of the overall proportion of strategy switching), whereby higher values indicate greater ER flexibility.

We conducted a preliminary check on whether the different context demands elicited correspondingly varying extents of ER strategy switching. As expected, frequency of reappraisal-to-distraction strategy switching was higher for high-, relative to low-, intensity negative images, $t(158) = 22.02$, $p < .001$, which is consistent with past findings indicating that reappraisal and distraction are preferred for low- and high-negative intensity levels, respectively (Scheibe et al., 2015; Sheppes et al., 2011).

Covariates

Fluid intelligence was measured using a short form of the Raven's Standard Progressive Matrices (RSPM-SF; Bilker et al., 2012). Participants solved nine geometric problems where they had to determine, by selecting from six to eight options, the missing segment that fitted each visual design. Higher proportion of correct responses signified better fluid intelligence. Depressive symptoms were assessed using a short form of the Center for Epidemiological Studies-Depression survey (CES-D-10; Andresen et al., 1994). Participants responded to 10 items related to depressive symptoms experienced in the past week (e.g., *"I felt depressed"*; 1 = *rarely or none of the time*, 4 = *most of the time*). Demographic data (e.g., gender) were extracted using a background questionnaire.

Binning Procedure

Bin scores were used to index performance on the shifting tasks as they afford higher reliability, validity, sensitivity in the detection of larger effect sizes, and factor coherence than do RT or accuracy scores (Draheim et al., 2016; Hughes et al., 2014; Toh & Yang, 2021). Bin scores were calculated based on procedures delineated by Draheim et al. (2016) as follows. First, at the within-subject level, trials that were (a) incorrect, (b) had reaction times (RTs) faster than 200 ms, or (c) had RTs that departed from each participant's mean by more than 3 *SD* were excluded. Next, each participant's mean RT for repeat trials was deducted from the RT of every accurate switch trial. Second, at the between-subject level, all difference scores were rank ordered as a group with bin scores assigned from 1 (fastest 10%) to 10 (slowest 10%). All inaccurate switch trials were given a bin score of 20. Third, for each participant, a single bin score was generated by averaging bin values for the accurate and inaccurate switch trials. Finally, bin scores were reverse coded such that higher values reflected better performance.

Procedure

Participants completed the study across two sessions, with a 1-day interval between each session. In the first session, the EF tasks were administered in the following order: keep-track, Stroop, animacy-locomotion, and Corsi block-tapping tasks. In the second session, participants first attempted the ER choice task, followed by the EF tasks which were conducted in the following order: antisaccade, colour-shape, two-back, go/no-go, and magnitude-parity tasks. Last, participants completed a series of questionnaires, which included CES-D-10 (i.e., depressive symptoms), RSPM-SF (i.e., fluid intelligence), and the demographic background questionnaire. The sequence of EF tasks was fixed for each participant, with the condition that no two consecutive tasks tapped the same EF dimension to minimise practice effects (Miyake et al., 2000). The entire study lasted approximately 3.5 hours.

Analysis Plan

All analyses were conducted on *Mplus* 8.5 (Muthén & Muthén, 2015) using full information maximum likelihood estimation. EF dimensions were modelled as latent factors. The indicators for inhibition were antisaccade, Stroop, and go/no-go tasks. The indicators for working memory were keep-track, two-back, and Corsi block-tapping tasks. The indicators for shifting were colour-shape, animacy-locomotion, and magnitude-parity tasks. All nine EF measures served as indicators for the common EF factor. For ER flexibility, switching frequency and switching variability were modelled as manifest variables. The covariates of gender, fluid intelligence, depressive symptoms, and reappraisal ability (i.e., residualized mean scores for the "Reframe" trials adjusted for mean scores on "Look Negative" trials) were manifest variables.

To determine that the manifest variables reflected their underlying latent constructs, confirmatory factor analysis was first performed to assess how well the measurement model fitted the data. Subsequently, structural equation modelling was conducted to assess the link between EF and the maintenance or switching of ER strategies. Specifically, we examined how the two indices of ER flexibility: (a) switching frequency at low- and high-intensity conditions, with the latter adjusted for baseline switching frequency at the low-intensity condition, and (b) switching variability, would be related to each independent EF dimension (i.e., inhibition, working memory, and shifting) as well as the shared (i.e., common EF) and unique (i.e., working-memory-specific and shifting-specific factors) EF components, based on the nested-factor model. Following which, we added the covariates (i.e., gender, fluid intelligence, depressive symptoms, and reappraisal ability) to examine whether the relations between EF and

ER strategy maintenance/switching would still hold when covariates were controlled for. Following recommendations by Hair et al. (2009) and Hu and Bentler (1998), we adopted the following model fit criteria: root-mean-square error of approximation (RMSEA) values equal to or lower than .08 (acceptable) and .06 (good), standardized root-mean-squared residual (SRMR) values equal to or lower than .08 (good), comparative fit index (CFI) close to or greater than .95 (good).

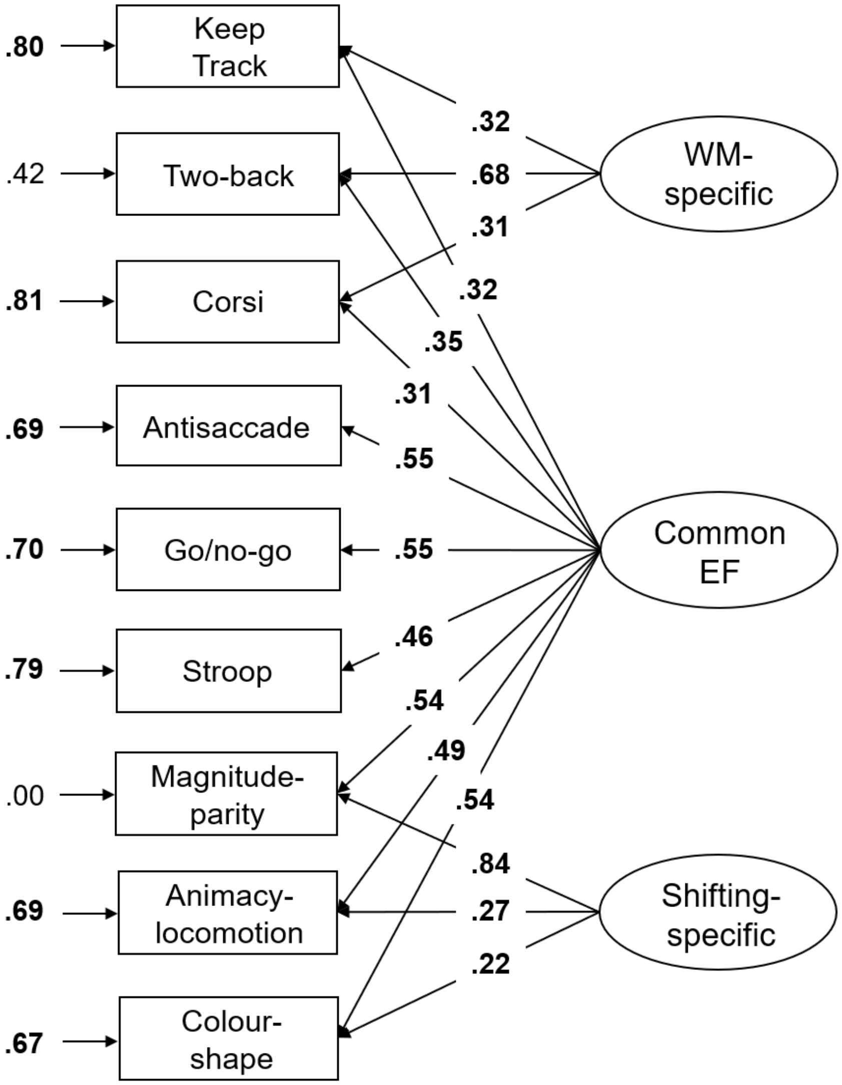
Results

Measurement Model

Confirmatory factor analyses indicated that the nested-factor EF model had a good fit to the data, and all factor loadings were significant (*p*s < .05, see Figure 1). Additionally, the small and nonsignificant residual variance for the magnitude-parity task ($\delta = .04$, $p = .95$) was constrained to zero to prevent negative residual variance in the subsequent structural models. Further, we compared the model fit of the nested-factor EF model to alternative EF models. Crucially, the nested-factor model provided a better fit to the data, relative to the one-, two-, and three-factor models (see Table 1). The confirmatory factor analyses demonstrate that the nested-factor EF model was the best-fitting model to the data.

Figure 1

Nested-Factor EF Model with Standardized Estimates



Note. Ovals represent latent variables and rectangles denote manifest variables. Values for the longer, single-headed arrows correspond to factor loadings, while values for the shorter, single-headed arrows signify error variances. Values for the curved, double-headed arrows signify interfactor correlations. With the exception of the nonsignificant residual variances for two-back and magnitude-parity tasks (*p*s > .24), all factor loadings and residual variances were statistically significant (as shown in boldface, *p*s < .05).

Table 1

Fit Indices for Measurement and Structural Models

	χ^2	*df*	RMSEA	SRMR	CFI
EF measurement models					
One-factor model	45.50	20	.083	.058	.882
Two-factor models					
Inhibition-WM merged	43.76	26	.061	.056	.925
Inhibition-shifting merged	38.28	26	.051	.049	.948
WM-shifting merged	57.39	26	.081	.064	.867
Three-factor model	28.93	24	.033	.041	.979
Nested-EF model	25.26	22	.028	.038	.986
Structural models					
Switching frequency					
WM					
Unadjusted model	3.93	4	.000	.040	1.00
Adjusted model[1]	16.54	12	.045	.036	.954
Inhibition					
Unadjusted model	4.61	4	.029	.026	.991
Adjusted model[1]	16.14	12	.043	.036	.964
Shifting					
Unadjusted model	10.02	4	.090	.049	.958
Adjusted model[1]	15.46	12	.040	.033	.978
Nested-factor model					
Unadjusted model	42.03	34	.036	.045	.972
Adjusted model[1]	80.26	58	.046	.046	.936
Switching variability					
WM					
Unadjusted model	0.71	2	.000	.014	1.00
Adjusted model[1]	12.13	10	.034	.030	.964
Inhibition					
Unadjusted model	0.09	2	.000	.005	1.00
Adjusted model[1]	13.40	10	.043	.035	.954
Shifting					
Unadjusted model	5.10	2	.062	.041	.978

Adjusted model[1]	11.27	11	.012	.036	.997
Nested-factor model					
Unadjusted model	28.17	28	.006	.037	.999
Adjusted model[1]	62.56	52	.033	.042	.964

Note. WM = working memory; RMSEA = root-mean-square error of approximation; SRMR = standardized root-mean-square residual; CFI = comparative fit index.

[1] Adjusted models include gender, intelligence, depressive symptoms, and reappraisal ability as covariates.

Structural Models

We proceeded with structural equation modelling to test the links between EF and the two indicators of ER flexibility. All structural models provided acceptable to good fit to the data (see Table 1) and standardised parameter estimates are shown in Table 2.

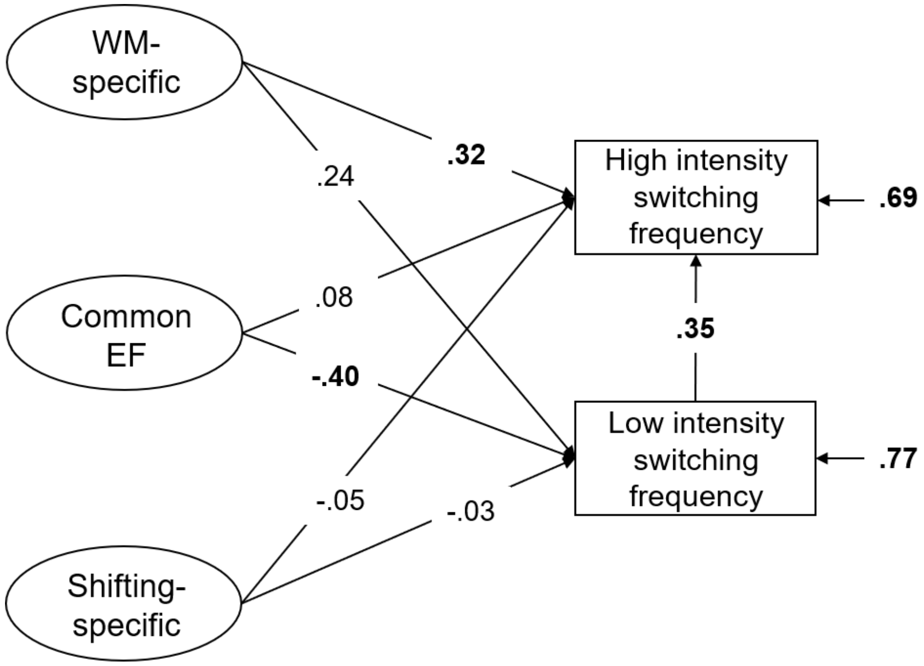
Switching Frequency

We first examined how the different EF dimensions would be implicated in ER strategy switching frequency at low- and high-intensity contexts. When the three EF facets were assessed individually, better working memory—but not inhibition and shifting ($|\gamma|$s < .13, *p*s > .38)—was concomitant with higher switching frequency (unadjusted: $\gamma = .24$, *SE* = .09, *p* = .011; adjusted: $\gamma = .35$, *SE* = .12, *p* = .003) at the high-, compared to low-, intensity condition. At the low-intensity condition, higher inhibition ($\gamma = -.30$, *SE* = .11, *p* = .006) and shifting ($\gamma = -.26$, *SE* = .09, *p* = .005) abilities were related to lower switching frequency; however, only the relation between shifting and switching frequency remained statistically significant when covariates were controlled for ($\gamma = -.37$, *SE* = .11, *p* < .001). Working memory was not linked to switching frequency at the low-intensity condition ($|\gamma|$s < .06, *p*s > .60). The findings from the independent assessment of EF factors allude that working memory and shifting abilities are implicated in ER strategy switching frequency during contexts with high and low levels of negative intensity, respectively.

For the nested-factor model, more proficient working-memory-specific ability was concomitant with higher switching frequency in the high-, relative to the low-, intensity condition (unadjusted: $\gamma = .31$, $SE = .13$, $p = .015$; adjusted: $\gamma = .32$, $SE = .13$, $p = .015$; see Figure 2). Common EF and shifting-specific factors were not related to switching frequency at high-, compared to low-, intensity situations ($|\gamma|$s < .08, ps > .54). Additionally, we found that common EF—but not working-memory-specific and shifting-specific factors ($|\gamma|$s < .24, ps > .11)—was negatively coupled with switching frequency (unadjusted: $\gamma = -.42$, $SE = .10$, $p < .001$; adjusted: $\gamma = -.40$, $SE = .14$, $p = .005$) for the low-intensity condition, but not the high-intensity condition ($|\gamma|$s < .08, ps > .59). In other words, better common EF was associated with higher frequency of strategy maintenance in low-intensity negative situations. Critically, the results from the nested-factor model qualify the findings when each EF factor was individually examined. Specifically, individuals with more proficient working-memory-specific ability indicate a more flexible pattern of ER strategy use, while common EF—and not shifting—is primarily involved in the maintenance of ER strategies during low-negative intensity contexts.

Figure 2

Structural Model of EF Dimensions Predicting Changes in Switching Frequency between Low and High Negative Intensity Conditions



Note. WM = working memory. Covariates and factor indicators are not shown for conciseness. Ovals represent latent factors and rectangles indicate manifest variables. Parameter estimates are standardised, and statistically significant values are shown in boldface (*p*s < .05). Values on the longer, single-headed arrows denote path coefficients; values for the smaller, single-headed arrows signify residual variances.

Switching Variability

Next, we examined the associations between EF and variability in ER strategy switching (see Table 2). For the independent EF factors, higher working memory was associated with greater switching variability (unadjusted: $\gamma = .23$, *SE* = .11, *p* = .030; adjusted: $\gamma = .35$, *SE* = .13, *p* = .007). Inhibition and shifting were not related to switching variability (|γ|s < .10, *p*s > .25). These results imply that working memory, but not inhibition and shifting, is correlated to ER strategy switching variability.

For the nested-factor model, better working-memory-specific ability corresponded with higher switching variability (γ = .35, *SE* = .14, *p* = .009), which held true when covariates were controlled for (γ = .38, *SE* = .14, *p* = .006). Common EF and shifting-specific factors were not affiliated with switching variability in both the unadjusted and adjusted models (|γ|s < .13, *p*s > .17). Together, converging findings from both the independent EF and nested-factor models highlight that better working-memory-specific abilities are predictive of greater variability in strategy maintenance and switching.

Table 2

Standardized Parameter Estimates for Switching Frequency and Switching Variability

	Low intensity switching frequency		High intensity switching frequency		Switching variability	
	Unadjusted	Adjusted	Unadjusted	Adjusted	Unadjusted	Adjusted
Working memory						
Focal predictor						
Working memory	-.06 (.11)	.04 (.14)	**.24 (.09)**	**.35 (.12)**	**.23 (.11)**	**.35 (.13)**
Covariates						
Gender	-	-.03 (.08)	-	-.09 (.08)	-	-.10 (.08)
Fluid intelligence	-	**-.22 (.10)**	-	-.15 (.10)	-	-.17 (.10)
Depressive symptoms	-	-.01 (.08)	-	.06 (.08)	-	.06 (.09)
Reappraisal ability	-	-.09 (.08)	-	-.10 (.08)	-	-.06 (.08)
Inhibition						
Focal predictor						
Inhibition	**-.30 (.11)**	-.30 (.16)	-.02 (.11)	.13 (.15)	-.05 (.10)	-.04 (.16)

Covariates						
Gender	-	-.04 (.08)	-	-.11 (.07)	-	-.12 (.08)
Fluid intelligence	-	-.02 (.13)	-	-.07 (.11)	-	.02 (.13)
Depressive symptoms	-	-.05 (.08)	-	.02 (.08)	-	.01 (.08)
Reappraisal ability	-	-.04 (.09)	-	-.08 (.08)	-	-.02 (.09)
Shifting						
Focal predictor						
Shifting	**-.37 (.09)**	**-.37 (.11)**	-.02 (.10)	.01 (.11)	.08 (.09)	.10 (.09)
Covariates						
Gender	-	-.01 (.08)	-	-.11 (.08)	-	-.13 (.08)
Fluid intelligence	-	-.10 (.08)	-	.01 (.08)	-	-.02 (.08)
Depressive symptoms	-	-.08 (.08)	-	.01 (.08)	-	.02 (.08)
Reappraisal ability	-	-.07 (.08)	-	-.06 (.07)	-	-.03 (.08)
Nested-factor model						
Focal predictors						
WM-specific	.22 (.14)	.24 (.15)	**.31 (.13)**	**.32 (.13)**	**.31 (.14)**	**.38 (.14)**
Common EF	**-.42 (.10)**	**-.40 (.14)**	-.03 (.12)	.08 (.15)	-.07 (.11)	.01 (.14)
Shifting-specific	-.01 (.10)	-.03 (.10)	-.03 (.08)	-.05 (.08)	.13 (.09)	.13 (.09)
Covariates						
Gender	-	.01 (.09)	-	-.09 (.08)	-	-.08 (.09)
Fluid intelligence	-	-.03 (.12)	-	-.11 (.11)	-	-.09 (.12)
Depressive symptoms	-	-.07 (.09)	-	.02 (.08)	-	.04 (.10)
Reappraisal ability	-	-.02 (.09)	-	-.07 (.08)	-	-.02 (.10)

Note. WM = working memory. Values denote standardized estimates with standard errors in parentheses. Significant values are marked in boldface, $p < .05$.

Discussion

Our findings indicate that different aspects of EF are asymmetrically associated with ER strategy maintenance and switching. First, we found that better working-memory-specific ability is concomitant with higher ER flexibility, as indicated by greater variability in strategy switching and higher switching frequency for high-, relative to low-, negative intensity contexts. Corroborating the role of working memory in ER strategy switching as postulated by the cognitive control framework of ER flexibility (Pruessner et al., 2020), our finding suggests that ER strategy switching entails the manipulation and updating of working-memory contents by replacing no-longer-relevant material with newer, more relevant information regarding the to-be-implemented ER strategy, as well as the controlled and strategic retrieval of essential ER information from long-term memory. This result dovetails, in part, with past work underscoring the integral contribution of working memory to cognitive flexibility (Blackwell et al., 2009) and theoretical accounts emphasizing the mechanistic role of working memory in the stability-flexibility tradeoff (Dreisbach & Fröber, 2019). Specifically, working memory facilitates cognitive flexibility by lowering updating threshold, thereby allowing easier access to new, incoming information, or by keeping multiple tasks active within mental workspace. To this end, future studies should investigate the mechanisms that underlie the relation between working memory and ER flexibility.

Second, we found that common EF was principally involved in the maintenance of ER strategies at low-intensity, but not high-intensity, negative contexts. For low-intensity negative situations, common EF—as a general goal-management ability—facilitates the implementation and maintenance of pertinent ER goals, while resisting attentional disruptions and interference from task-irrelevant information and distractions. Converging with the literature on how lapses in sustained attention and goal maintenance are concomitant with poor impulse control (Friedman et al., 2020), our finding alludes that lower common EF may be symptomatic of strategy instability, marked by haphazard and premature strategy switching that prevents the maintenance of an initially implemented—and possibly effective—ER strategy (Sheppes et al., 2015). Consistent with this notion, past work has shown that individuals with more impoverished inhibition abilities (as assessed by the flanker task) tend to choose the less cognitively exacting ER strategy of distraction over reappraisal (Scheibe et al., 2015).

For high-intensity negative situations, however, the overwhelming contextual demands exert strong influences on mental gear shifting operations that promote switching to a more adaptive ER strategy (i.e., distraction), which likely override common EF processes involved in maintaining the initial ER strategy (i.e., reappraisal). Importantly, we show that the effect of common EF on ER strategy maintenance is dependent on contextual factors. Additionally, our results cohere with empirical evidence highlighting that the links between common EF and behavioral outcomes (e.g., explicit racial bias, smartphone checking frequency) are contingent on modulating variables (e.g., implicit impulses, problematic smartphone tendencies; Ito et al., 2015; Toh et al., 2021). Critically, it is notable that working-memory-specific and common EF factors are uniquely associated with the decision to switch and maintain ER strategies, respectively, above and beyond third-variable effects (i.e., gender, intelligence, and depressive symptoms) and—more importantly—how successful one is in reappraising negative content (i.e., reappraisal ability). Together, our findings underscore the utility of assessing EF as a multidimensional construct by demonstrating that different EF facets are divergently associated with ER maintenance and switching.

Despite the positive findings, some of the postulations of the cognitive control framework of ER flexibility (Pruessner et al., 2020) were not supported. For ER strategy switching, we failed to find evidence for the role of inhibition in the propensity to switch strategies. While this null result implies that ER strategy switching does not implicate the EF ability to inhibit the inclination to continue with the previous strategy, it is possible that the inhibitory processes assessed in our study (i.e., the ability to resolve interference from prepotent responses) are not involved in ER strategy switching. Notably, our ER choice paradigm requires the engagement with a predetermined ER strategy (i.e., reappraisal) which may not necessarily constitute the habitual or dominant ER strategy for certain individuals. Correspondingly, switching to a subsequent ER strategy (i.e., distraction) may not entail the inhibition of a prepotent tendency to sustain the initial ER strategy. Further, given the multifarious nature of inhibitory processes (Friedman & Miyake, 2004), it remains unknown whether other forms of inhibition, such as proactive interference (i.e., suppressing memory intrusions from no-longer-relevant information), could be linked to ER strategy choice. Therefore, future research should employ ER choice paradigms that more closely align with the specific type of inhibition that is being studied, as well as identify which inhibitory operation(s) is/are implicated in ER flexibility.

Additionally, we found that ER strategy switching does not involve shifting-specific ability. Contrary to the predictions from the cognitive control framework of ER flexibility (Pruessner et al., 2020), our findings indicate that higher shifting—when assessed independently from other EF facets—was associated with lower likelihood of ER strategy switching (i.e., higher frequency of ER strategy maintenance at low-intensity situations). Critically, findings from the nested-factor model clarified that the link between shifting and ER strategy maintenance was driven by common EF, rather than shifting-specific processes. A possible explanation for the null result for shifting-specific processes is that while ER strategy switching involves switching from a suboptimal to a more optimal strategy, it may not necessarily reflect the continuous switching between multiple mental sets that is representative of shifting abilities as assessed by task-switching paradigms (Monsell, 2003). Rather, during ER strategy switching, once a desired strategy has been chosen, further switching is unlikely. Hence, in comparison to working memory, ER strategy switching does not seem to extensively involve shifting abilities. Nevertheless, further replications of our work are needed to confirm these speculations.

Moreover, there was a lack of support for the link between working-memory-specific ability and ER strategy maintenance. Pruessner et al. (2020) hypothesized that working memory may be needed for the attentional focus and maintenance of ER goals and strategies within mental workspace, based on past findings highlighting the role of working memory in ER strategies (e.g., reappraisal; Schmeichel & Tang, 2015). However, it should be noted that the ability to maintain task-relevant information while resisting interference from task-irrelevant distractors (i.e., common EF), is a core mechanism in working memory performance (Engle & Kane, 2004). Indeed, a previous study demonstrated that the relation between working memory and reappraisal is primarily accounted for by common EF, rather than working-memory-specific processes (Toh & Yang, 2021). Likewise, we show that it is common EF, but not working-memory-specific and shifting-specific components, that undergirds the choice to maintain ER strategy in low-intensity situations. Pivotally, our findings underscore the importance of estimating EF using a nested-factor model, which partitions the shared and unique aspects of EF facets, to more precisely identify the EF component(s) that is/are coupled with ER flexibility.

Several limitations of the current research should be noted. First, the correlational nature of our study limits causal inferences. Although we assume that EF predicts ER flexibility, it is possible that ER flexibility influences EF instead. For instance, given that the successful implementation of ER strategies engages EF processes (Schmeichel & Tang, 2015), the persistent and varied use of different ER strategies may pose novel demands on EF processes, which may translate into gains in EF over time (Diamond, 2013). Accordingly, longitudinal designs and training studies are needed to ascertain the directionality between EF and ER flexibility.

Second, although reappraisal and distraction are the most commonly examined ER strategies in the ER flexibility literature (e.g., Birk & Bonanno, 2016; Sheppes et al., 2014), the links between EF and the flexible implementation of other ER strategies are unknown. Notably, individuals employ an average of four ER strategies on a daily basis (Eldesouky & English, 2018) and certain types of ER strategies are habitually used by some individuals more than others (e.g., reappraisal, situation selection, and distraction; Moreira et al., 2021). Further, the self-reported negative emotions elicited from the affective stimuli employed in our study may not necessarily correspond to those generated via other media types (e.g., music and films) or daily experiences, which likely differ in personal relevance and ecological validity (Ellard et al., 2012; Rottenberg et al., 2007). Therefore, it remains to be seen whether similar patterns of results would be obtained using other emotion-eliciting stimuli or modes of assessment (e.g., psychophysiological and experience-sampling methods). In this regard, future work would benefit from more comprehensive, multimodal assessments of ER strategies to obtain richer profiles of how individuals flexibly employ ER strategies in response to fluctuating situations.

Third, our results can only speak to the relations between EF and ER strategy switching from reappraisal to distraction. An alternative account of our findings is that EF predicts the general, nonspecific switching from an initial ER strategy to a subsequent ER strategy. As only reappraisal-to-distraction (but not distraction-to-reappraisal) strategy switching was tested in our study, we are unable to definitively examine this possibility. However, it should be noted that distraction-to-reappraisal switching reflects a nonoptimal pattern of strategy, owing to conflicting motivations in the desire to (a) switch strategies when one’s negative affect has not been sufficiently reduced by distraction, and (b) continue using distraction for high-intensity negative situations, given that it is less cognitively taxing and more adaptive than reappraisal under such circumstances (e.g., Levy-Gigi et al., 2016). Correspondingly, distraction-to-reappraisal switching has been shown to be unrelated to emotional intensity (i.e., valence and arousal) as well as individual-difference factors, such as responsiveness to feedback from internal states (e.g., corrugator activity, heart rate deceleration) and well-being (Birk & Bonanno, 2016). Therefore, it is unclear whether distraction-to-reappraisal switching would be associated with individual differences in EF processes that are responsible for ER strategy switching during high-intensity situations. Nevertheless, future research should ascertain whether EF would be more strongly associated with the more optimal reappraisal-to-distraction condition versus the suboptimal distraction-to-reappraisal condition.

Fourth, as our study focused on ER strategy maintenance and switching, our findings are silent on the associations between EF facets and monitoring processes (i.e., the continuous monitoring of potential discrepancies between regulatory efforts and changing contextual goals) that are involved in ER flexibility (Pruessner et al., 2020). According to the cognitive control framework of ER flexibility, working memory facilitates ER monitoring processes by lowering updating threshold, thereby allowing for new information and contextual fluctuations to be more easily detected (Pruessner et al., 2020). Further, it is unknown whether EF could be implicated in other aspects of ER flexibility, such as context sensitivity (i.e., awareness and evaluation of contextual demands), repertoire (i.e., availability of strategies that can be enacted), and feedback responsiveness (i.e., capacity to monitor effectiveness of ER strategy and modify as needed; Bonanno & Burton, 2013). Hence, further work is warranted to uncover the EF correlates of the various ER flexibility components.

Fifth, as the sample recruited for this study comprised young adults, our findings may not be generalizable to other age groups. According to the socioemotional selectivity theory, the awareness of limited time horizons motivates older adults to actively regulate their emotions in service of positive emotional experiences (Carstensen, 2006). To achieve this, older adults have been averred to invest a larger portion of their cognitive resources into ER processes, as evidenced by their preference for positive, over negative, information with regard to attention, memory, and decision-making processes than do their younger counterparts (Mather & Carstensen, 2005). Alternatively, older adults may prioritise ER strategies that are less cognitively demanding to maximise positive emotions (Opitz et al., 2012; Urry & Gross, 2010). For instance, older adults prefer distraction over the more cognitively exacting ER strategy of reappraisal when modulating emotional responses to high-intensity unpleasant pictures (Martins et al., 2018; Scheibe et al., 2015). Correspondingly, more research is warranted to uncover potential age-related differences, as well as their underlying mechanisms, in the link between EF and ER flexibility among younger and older adults.

In summary, our study contributes to the burgeoning empirical interest in ER flexibility by delineating how EF facets are linked to ER strategy maintenance and switching across different situations. Using latent-variable analysis and nested-factor modelling, our findings show that the flexible switching of ER strategies principally entails the working-memory-specific ability to manipulate and update affective information within mental workspace, whereas ER strategy maintenance predominantly recruits the common EF ability to maintain ER goals while resisting irrelevant information at low-intensity contexts. Crucially, our results provide an initial test of the cognitive control framework of ER flexibility (Pruessner et al., 2020), and positions EF as a critical cognitive factor that biases EF strategy choice in accord with contextual demands.

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Appendix A

Table A

Descriptive Statistics and Zero-Order Correlations between Variables of Interest

	M	*SD*	Min	Max	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Predictors[1]																				
1. Keep track	0.79	0.09	0.42	0.96	-															
2. Two-back	0.94	0.05	0.77	1.00	**.32**	-														
3. Corsi	64.03	22.74	0.00	112.00	**.21**	**.34**	-													
4. Antisaccade	0.63	0.21	0.25	0.99	**.22**	**.27**	**.19**	-												
5. Go/no-go	0.44	0.18	0.00	0.88	**.19**	.12	.08	**.32**	-											
6. Stroop	0.9	0.08	0.54	1.00	**.21**	**.17**	**.21**	**.17**	**.29**	-										
7. Magnitude parity[2]	13.13	2.16	6.48	17.37	.12	**.20**	.13	**.27**	**.37**	**.23**	-									
8. Animacy locomotion[2]	13.55	2.58	2.87	18.07	.11	**.15**	**.18**	**.32**	**.20**	**.26**	**.49**	-								
9. Colour shape[2]	13.69	2.09	5.15	18.17	.09	.14	**.25**	**.29**	**.30**	**.27**	**.47**	**.32**	-							
Criterion[3]																				
10. Low-intensity switching frequency	0.11	0.18	0.00	1.00	-.09	-.05	.11	**-.20**	**-.16**	-.12	**-.22**	**-.17**	**-.36**	-						
11. High-intensity switching frequency	0.47	0.20	0.00	1.00	.09	.13	**.18**	-.01	-.11	-.12	-.12	-.03	**-.18**	**.43**	-					
12. Switching variability	0.43	0.07	0.18	0.51	.14	.13	.11	-.03	-.03	-.04	.07	.06	-.08	.09	**.64**	-				

Covariates																				
13. Reframe trials[4]	4.07	1.05	1.33	6.20	.12	.03	.10	**.24**	.10	.14	**.15**	.04	.12	**-.21**	**-.22**	-.13	-			
14. Baseline trials[4]	3.30	1.02	1.13	5.87	-.02	.08	.10	**.17**	.02	.01	.13	.01	**.18**	**-.18**	**-.18**	**-.16**	**.61**	-		
15. Gender (% female)[5]	70.50	-	-	-	-.04	.01	.02	.01	.06	.10	.07	.06	.10	-.06	-.14	-.12	**.20**	**.17**	-	
16. Fluid intelligence	6.16	1.84	1.00	9.00	**.26**	**.22**	**.28**	**.46**	**.22**	**.19**	**.22**	**.15**	**.28**	**-.20**	-.10	-.03	**.28**	**.20**	.08	-
17. Depressive symptoms	2.13	0.60	1.10	3.80	-.14	-.02	.01	-.04	**-.16**	-.02	**-.15**	-.09	**-.15**	-.01	.03	.03	.02	-.06	**-.19**	-.04

Note.

[1] Due to technical problems, there were missing data for the following EF tasks: keep track (*n* = 1), two-back (*n* = 6), Stroop (*n* = 9), and animacy-locomotion (*n* = 1). Additionally, a procedural error resulted in the Corsi block-tapping task not being administered to 22% of the participants (*n* = 40).

[2] For the magnitude-parity, animacy-locomotion, and colour-shape tasks, bin scores were reverse-coded such that higher values indicate better performance.

[3] ER strategy switching frequency reflected the proportion of strategy switching for the low- and high-intensity conditions. Switching variability was represented by each participant's standard deviation of the proportion of overall strategy switches. Following Birk and Bonanno (2016), we excluded participants (*n* = 25) who showed no variation in ER strategy switching (i.e., either did not switch at all or switched all the time).

[4] Reappraisal ability was indexed by mean scores on reframe trials, adjusted for mean scores on baseline (i.e., "Look Negative") trials. All scores for reframe and baseline trials were reverse coded such that higher values represent higher levels of reappraisal ability.

[5] Gender was coded as 0 = *female*, 1 = *male*.