Self-Regulatory Processes: Relationships Between Executive Function, Emotion Regulation, the Experience of Emotions and Psychological Distress.

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

Although executive function (EF) and emotion regulation (ER) are both self-regulatory abilities which share common neural substrates and have been linked to common mental health outcomes, few research studies have looked at the direct relationship or considered common underlying factors that may influence this relationship. The current study examined the relationships between ER strategy use, EFs, and their joint and independent effects on the experience of emotions and psychological distress in an undergraduate sample. In the current study we assessed ER, emotional reactivity, the experience of affect and psychological distress using self-report. We measured individuals on a battery of EF tasks. Based on previous research we predicted that increased use of cognitive reappraisal would be related to better inhibition and working memory and healthier psychological functioning. Conversely, we predicted that increased use of expressive suppression would be related to weaker inhibition and working memory and increased reporting of psychological distress. Additionally, we predicted that emotional reactivity would moderate the effects of EF and ER on psychological outcomes. Results indicated that neither inhibition nor working memory were associated with ER strategy use. Conversely, increased use of cognitive reappraisal predicted higher positive emotions, while increased use of expressive suppression predicted higher negative emotions and increased psychological distress. Furthermore, better inhibition was predictive of increased psychological distress. Finally, emotional reactivity added predictive power to negative affect and psychological distress and there was a moderating effect of emotional reactivity on the predictive ability of inhibition on negative affect. We discuss the research implications of these findings and suggest directions for future research in this area.

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Introduction

This literature review examines executive functions (EF), emotion regulation (ER) and research supporting an association between these two concepts. Developmental trajectories and neural substrates of both EF and ER are discussed to potentially highlight some common underlying features of these constructs. In addition, common correlates of EF and ER, such as psychological distress and emotional reactivity are reviewed.

1. Executive Functioning

Executive functions are typically viewed as processes used to self-regulate one's thoughts and behaviours towards a goal (Alvarez & Emory, 2006). The following reviews unitary, componential, and integrative perspectives of EF. It should be noted that, though not a complete analysis of perspectives of EF, this review attempts to evaluate and consolidate the most influential models to date and discuss them in a developmental framework.

1.1 Unitary models of EF

Executive function was traditionally conceptualized as a unitary construct in which a singular underlying ability controlled goal-oriented thoughts and behaviours (Goldstein, Naglieri, Princiotta & Otero, 2014). Ideas regarding the nature of this unitary ability were influenced by early work conducted by Broadbent (1958) using a dichotic listening task. In this task, participants were asked to answer one question after being presented with two questions simultaneously. Participants were more accurate at answering the question correctly when they were instructed to attend to a question asked through one side of the headphones and to neglect what was being asked through the other side of the headphones (Broadbent, 1958). This finding led to the inference that when participants are directed to selectively attend to one stimulus rather than another, they can better control which information to attend to by blocking out task-irrelevant information.

The notion of a limited capacity attentional system suggests that some kind of cognitive processing enables us to actively attend to certain information while filtering out other information in order to effectively complete a goal. Posner and Boies' (1971) model of attention suggested that this processing capacity was determined by a central limited capacity system which controlled attentional sub processes such as alerting and selectivity. Alerting prepares one's attention for deployment towards an external or internal stimulus, whereas selectivity refers to the ability to attend to certain stimuli while ignoring others. For example, when an individual hears a loud sound, their alerting system may queue them to attend to the location of that stimulus and the selectivity system would enable them to focus on the loud sound rather than competing sources of information in the environment. In this model, the central limited capacity system is synonymous with EF.

Following Posner and Boies' research on attention, Baddeley and Hitch's (1974) classic model of working memory was postulated as being central to goal completion. Their model was initially based upon Atkinson and Shiffrin's (1968) model of memory which suggested that sensory information that was attended to and rehearsed in short-term memory was eventually encoded into long-term memory. Thus inherent in this model was the assumption that if the short-term encoding system was damaged then information would not make it into long-term memory. However, brain injury patients with impairments to short-term memory areas were still capable of encoding information into long-term memory (Shallice & Warrington, 1970). Moreover, dual-task experiments where participants were required to do two working memory tasks simultaneously suggested the presence of two distinct temporary stores dedicated to verbal and visual-spatial information, as participants were able to perform above chance levels on the secondary working memory task provided that it did not tap into the same store (Baddeley & Hitch, 1974). Furthermore, research by Posner and Boies (1971) found that the encoding of visual information did not interfere with performance on alerting and selectivity tasks, suggesting that encoding does not interfere with processing capacity and that encoding of sensory information relies on a system separate from that of executive attention. Accordingly, Baddeley and Hitch expanded upon the short-term store put forth by Atkinson and Shiffrin by suggesting a new model that was used to temporarily store and manipulate sensory information which consisted of three components. This new model of memory was referred to as working memory and consisted of two slave systems, the visuo-spatial sketchpad and the phonological loop, which were controlled by an attentional system called the central executive (Baddeley & Hitch, 1974). The visuo-spatial sketchpad was thought to be responsible for holding and manipulating visual information, while the phonological loop was thought to be used for temporary storage and manipulation of verbal information. The central executive was proposed to be a primary tenet of EF. Accordingly, the central executive was conceptualized as a system that directs attention to and temporarily stores information from the two slave systems (Baddeley & Hitch, 1974). More recently, Baddeley has suggested that the central executive has several other functions, including more of an attentional focusing role that is similar to that proposed by Posner and Boies, as well as a role in long-term memory retrieval (Baddeley, 1996). Finally, the central executive has been related to the supervisory attention system postulated by Norman and Shallice (1986) which is described below.

In contrast to the models suggested by Baddeley and Hitch (1974) and Posner and Boise (1971), which viewed executive attention in its relation to perceptual stimuli, Norman and Shallice's

(1986) model, known as the supervisory attention system (SAS), focused more internally on the mind's control of action. According to this model, in any given situation we activate various schemata that are used to guide our actions more or less automatically. However, a resolution system is required when many schemas are activated at the same time, or when an active schema conflicts with a desired goal (Norman & Shallice, 1986). Norman and Shallice (1986) postulated that internal schemas have organizational values that create an internal hierarchy to reduce conflict, although these values can be indirectly influenced through motivational factors and attentional control resources. This latter influence on control of action is referred to as the SAS and is often required during completion of novel and complex tasks (Norman & Shallice, 1986). Norman and Shallice further suggested that this control of action is applied consciously and as such will increase the time needed to complete the task. As conscious control processes are thought to be completed one after another and not concurrently, the more conscious control that is applied by the SAS will further modulate the time needed to complete the task (Norman & Shallice, 1986).

None of the unitary models described thus far were intended to explain EF in a developmental context; however, there are two well-known unitary conceptualizations of EF that have been developed with a developing population in mind. One of the most influential developmental models of EF is the cognitive complexity and control (CCC) theory devised by Zelazo and Frye (1998). Based on the findings of several variations of card sorting tasks, Zelazo and colleagues have found that preschoolers aged 3 to 4 perform poorly when asked to switch their sorting criteria while 5-year olds successfully switch between sorts (e.g., first sorting by colour, then sorting by shape: Jacques, Zelazo, Kirkham & Semcesen, 1999; Zelazo, Frye & Rapus, 1996; Zelazo & Frye, 1998; Zelazo, Muller, Frye & Marcovitch, 2003). Alternative explanations of preschoolers' performance on this task, involving limitations in their working memory and/or inhibition, do not fully account for these findings, as other studies have demonstrated that young children are able to correctly identify which rule they are supposed to be following despite perseverating on this task (Zelazo et al., 1996), can successfully sort by colour and shape at the same time (i.e., sorting cards into four piles as opposed to two: Zelazo & Frye, 1998), and perseverate even after being exposed to only one pre-switch trial (Zelazo & Frye, 1998**).** Thus, according to CCC theory, EF reflects the ability to represent rules in a hierarchical fashion, starting with being able to represent a single rule and adding increasing layers of complexity through development (Zelazo & Frye, 1998).

A similar developmental conceptualization of EF is provided by Munakata, Snyder and Chatam (2012), who propose that the development of abstract goal representations and increases in cognitive flexibility coincide with successful goal-directed behaviours. According to their model, we are initially regulated through external sources such as environmental cues and other individuals. For example, an infant will look towards a parent's voice, or a child will go to their room when instructed to do so. These externally motivated cues are said to be reactive forms of regulation and infants and young children are considered to be unable to effectively represent future-oriented goals (Munakata et al., 2012). As we develop, it is suggested that we become increasingly internally self-regulated and develop the ability to represent goals in a proactive way. As such, we may use internal cues, such as self-directed speech to switch between and plan tasks effectively (Munakata et al., 2012).

The unitary models of EF that have been presented thus far all involve one underlying ability that contributes to success in the regulation of goal-oriented behaviour. These models suggest that EF is a limited capacity system that facilitates processing of and responses to goal-relevant information – particularly in the presence of irrelevant and/or competing information – and that may be mastered via developmental changes in mental representations of complex rules and goals.

1.2 A componential model of EF

In contrast to the unitary models discussed above, componential models of EF posit that multiple processes subserve EF. One influential componential model has been proposed by Nigg (2000). Though his model focuses on inhibition as being central to the executive construct, it identifies 4 types of effortful inhibition systems that comprise EF. These inhibitory systems consist of motor and cognitive interference control, behavioural inhibition, and oculomotor inhibition. Nigg (2000) also outlines automatic and personality models of inhibition. As EF is typically related to conscious control of thoughts and behaviour, the latter models will not be reviewed here.

The first and perhaps most well researched form of effortful inhibition is interference control. This can involve both actively suppressing external stimuli from interfering with an action and purposefully ignoring internal information that may disrupt task performance (Nigg, 2000). An example of the former has been referred to by Nigg as motor inhibition. This form of inhibition was postulated due to the observation that individuals take longer to respond when in the presence of external distractors (Nigg, 2000). Another example of interference control is cognitive inhibition. This type of inhibition refers to the suppression of irrelevant cognitions to maintain available cognitive resources such as working memory or visual attention (Nigg, 2000).

Another type of inhibition described through Nigg's model is behavioural inhibition. Behavioural inhibition requires the suppression of a prepotent, but incorrect response to a stimulus (Nigg, 2000). This means that individuals must actively stop themselves from performing an overlearned and somewhat automatic response. Although tasks assessing interference control often include the suppression of a prepotent response, these tasks are separable from behavioural inhibition tasks in the sense that they also require participants to actively ignore distractor stimuli to make a decision (Nigg, 2000).

The final effortful control of inhibition suggested by Nigg (2000) is oculomotor inhibition. This view of inhibition involves the effortful suppression of reflexive eye movements to novel, but irrelevant visual targets. This would also include the inhibition of saccadic eye movements to information in one's periphery which may not demand our attention externally, such as looking towards a flashing light, or hearing a loud noise. Rather we may orient to these locations out of a failure to inhibit internal desires to attend to them.

In general, Nigg's (2000) model of inhibition proposes that effortful inhibition represents a complex set of executive abilities that assist with goal completion. While unitary models of EF propose that a single function controls our thoughts and actions towards goals, Nigg (2000) suggests that multiple systems of inhibitory control determine our ability to successfully pursue a goal.

1.3 An integrative framework of EF

An alternative view to the unitary and componential views of EF is an integrative perspective of EF. According to Miyake and colleagues' (2000) unity and diversity framework, EF is a set of interrelated, but separable constructs that aid individuals in the effortful self-regulation of their thoughts and actions towards a specific goal.

In their review of current studies using performance measures of EF, Miyake and colleagues (2000) note that correlations between various executive tasks tend to be low (i.e., < 0.4) and that exploratory factor analyses of these tasks typically find more than one factor. These findings suggest that EF is not unitary. Owing to EF's non-unitary nature, the authors also noted that performance measures of EF have a task impurity problem such that each executive task necessarily measures more than what it is specified to assess. Moreover, the authors observed that many tasks assessing EF have low internal reliability, which further indicates that they measure more than just what they are supposed to measure. To overcome the task impurity problem posed by performance measures of EF, the authors modeled the unique variance from each executive task and used the ensuing latent factors in confirmatory factor analysis (Miyake et al., 2000).

The three major factors that Miyake and colleagues (2000) focused on were inhibition of prepotent responses, updating and monitoring of working memory representations, and shifting between task demands. Inhibition refers to the deliberate process of stopping oneself from performing a prepotent response and is similar to Nigg's (2000) description of behavioural inhibition. Updating includes actively updating, monitoring and coding task-relevant information. Rather than passively storing and maintaining information, as is suggested in Baddeley and Hitch's (1974) conceptualization of working memory, updating also includes the ability to manipulate the contents of working memory (Miyake et al., 2000). Lastly, shifting is the ability to switch attention between tasks or mental sets, which requires individuals to disengage from an irrelevant task or mental set in order to engage in a relevant task or mental set, and is similar to the supervisory attention system postulated by Norman and Shallice (1986). Miyake et al. (2000) focus on these three executive skills because they have been well studied, are viewed as being more central to the executive construct, and relatedly, are thought to be required for more complex forms of EF. Inhibition, updating, and shifting are believed to be heavily supported by the frontal lobes, based on brain lesion, neuropsychological and neurophysiological studies (Casey et al., 1997; Everling & Fischer, 1998; Goldman-Rakic, 1996; Guitton, Buchtel & Douglas, 1985; Kiefer et al., 1998; Perret, 1974; Posner & Raichle, 1994; Smith & Jonides, 1999; Stuss, Eskes & Foster).

Confirmatory factor analysis supported a three-factor model of executive function. The three-factor model with inter-related factors was a significantly better fit than a model in which all three factors were independent, suggesting that the three executive skills are separable but share a significant amount of variance and are thus better understood when analyzed together (Miyake et al., 2000).

1.4 Development of EF

Miyake and colleagues' (2000) model of EF was developed using data from young adults and – unlike models put forward by Zelazo and colleagues and Munkata and colleagues – does not attempt to explain how EF unfolds between infancy and young adulthood. Nonetheless, the 3-factor model of EF put forward by Miyake et al. has been replicated in children as young as 6 years of age and age-related improvements in the 3 core EF skills has been studied extensively in children and adolescents (Huizing, Dolan & van der Molen, 2006; Lehto, Juujarvi, Kooistra & Pulkkinen, 2003; McAuley & White, 2010; Van der Ven, Kroesbergen, Boom & Leseman, 2013).

One study examining the structure and development of EF was conducted by Huizinga et al. (2006), using an approach similar to that of Miyake et al. (2000). This study was conducted with individuals 7-21 years of age, who were administered tasks assessing core EF skills. Composites of working memory and shifting were significantly correlated, but only moderately so, which lends support to a developmental unity and diversity model similar to the adult model developed by Miyake and colleagues (2000). Contrary to expectation, however, the inhibitory tasks did not converge on a single construct which may indicate that inhibition is multi-dimensional during development. Regarding age-related change in executive skills, the authors found that working memory had the most protracted rate of development and did not plateau until age 15. Shifting had the second longest rate of development, as shift costs decreased significantly until 11 years of age (Huizinga et al., 2006). When looking at individual inhibitory tasks, performance on the Eriksen Flanker and Stop-signal tasks reached adult levels around age 11, while performance on the Stroop task did not show a developmental trend and was more associated with age related improvements in processing speed (Huizinga et al., 2006). Composites of working memory, shifting, the Eriksen Flanker task and the Stop-signal tasks were also related to basic speed. However, these age-related changes remained significant even when controlling for basic speed. These results suggest that composites of working memory and shifting, and individual tasks of inhibition develop at somewhat different rates, while remaining correlated with each other, which offers additional support for the unity and diversity framework (Miyake et al., 2000). It also implies that these abilities become separable at different ages through the differential development of each ability.

Consistent with these results, a similar study by Lehto and colleagues in a sample of children and adolescents aged 8 to 13 found that shifting and working memory developed significantly with age while inhibition did not (Lehto et al., 2003). Additionally, in support of Miyake and colleagues unity and diversity framework, the researchers found that a three-factor model of EF including working memory, inhibition, and shifting fit the data better than a unitary or two-factor model of EF (Lehto et al., 2003). Based on the aforementioned developmental research, it would seem that working memory and shifting have the most protracted developmental course and that inhibition may see the greatest improvements prior to age seven.

Another developmental research study consistent with the unity and diversity framework of EF carried out by McAuley and White (2010) found that inhibition, working memory and processing speed are separable abilities across participants aged 6-24. Results of confirmatory factor analysis across all ages suggested that a three-factor model of EF including processing speed, response inhibition, and working memory fit better than a unitary model of EF, or any two-factor models (McAuley & White, 2010). Additionally, McAuley and White (2010) found significant increases in these abilities with age, with the most marked increases occurring from early to late childhood. However, when the effects of processing speed were controlled for, only the linear effect of age on working memory remained significant. This is consistent with work by Huizinga and colleagues which found that working memory, inhibition and shifting have a protracted course of development which is largely mediated by concurrent increases processing speed (McAuley & White, 2010). This study also replicates and extends the findings from previous research suggesting that EF's are separable constructs even as young as six years of age (Huizinga et al., 2006; Lehto et al., 2003).

A meta-analysis by Best and Miller (2010) has conducted an in-depth examination of developmental models of EF and has found similar results to the aforementioned research studies. Regarding inhibitory control, results seem to indicate that inhibition develops greatly in early childhood and reaches a ceiling between ages 7 and 12. Studies looking at working memory found that working memory makes significant improvements until 16 years of age (Best & Miller, 2010). Concerning the development of shifting, Best and Miller (2010) report that developmental studies have found considerable change in set shifting ability from around age 4 until adolescence, reaching adult levels around age 15 (Best & Miller, 2010).

A single strongly supported theoretical perspective is necessary to evaluate the measurement of executive abilities through research; however, what is more important lies within the similarities between conceptualizations of EF. Although we support the unity and diversity framework of EF, it is clear that all conceptualizations of EF share in common the idea that EF involves the ability to self-regulate thoughts and behaviours towards a goal.

2. Emotion Regulation

Another self-regulatory ability, emotion regulation (ER), has been a topic of increasing interest over the past 20 years. Over this time, various conceptualizations of what ER entails have been put forth. Typically these models share the idea that ER involves the active management of emotions in pursuit of an emotional goal (Gross, 1998b; Koole, 2009; Parkinson & Totterdell, 1999; Southam-Gerow & Kendall, 2002; Thayer Newman & McClain, 1994; Thompson, 1994; Thompson, 2011). In this way, ER is generally similar to EF in the sense that it requires an individual to monitor internal and external information, and apply changes towards a desired goal. Also like EF, ER has several similar models defining what it entails. Of note, this review aims to examine the construct of ER, which is thought to be somewhat different from other forms of affect regulation, including mood regulation which refers to self-regulation of mood states, and coping which focuses on the reduction of stress. These latter constructs are not included in the review.

2.1 Models of ER

Affect regulation

A broad conceptualization of affect regulation which encompasses emotion regulation, coping, and mood regulation has been put forth by Parkinson and Totterdell (1999) who suggest that there are two overarching types of affect regulation. The first, automatic refers to over-learnt affect regulation strategies that occur outside of conscious awareness, but still work towards changing a felt emotion. This type of affect regulation is thought to be well engrained and is primarily utilized to help maintain emotional homeostasis (Parkinson & Totterdell, 1999). Conversely, controlled affect regulation is suggested to involve deliberate manipulation of mood states through some regulation strategy which is implemented, monitored and terminated based on a desired affective state (Parkinson & Totterdell, 1999). This latter form of affect regulation is more similar to what is focused upon in articles which define mood regulation, emotion regulation and coping (Gross, 1998b; Skinner, Edge, Altman & Sherwood, 2003; Thayer et al., 1994). Accordingly, the scope of this paper will include a focus on controlled affect regulation.

Parkinson and Totterdell’s (1999) taxonomy of affect regulation strategies identified a broad spectrum of ER strategies. Their model was based on Thayer and colleagues’ (1994) conceptualization, but aimed to overcome some of the limitations identified in Thayer et al.’s model (Parkinson & Totterdell, 1999). Primarily, the authors wanted to include an exhaustive list of affect regulation strategies that would be derived through a theoretical perspective of affect regulation. Facets of affect regulation strategies could then be tested through confirmatory factor analysis.

Using this perspective, the authors created an extensive list of affect regulation strategies consisting of 162 strategies with six higher-level distinctions (Parkinson & Totterdell, 1999). The higher-level distinctions postulated consisted of behavioural versus cognitive implementation mediums, diversion versus addressing strategies, active versus passive diversion from the troubling thought or feeling, direct versus indirect benefits provided by the strategy, active versus passive addressing of the thought or feeling, and situation-directed versus affect-directed strategies for addressing mood state (Parkinson & Totterdell, 1999). These higher-level distinctions were further broken down into sub-clusters, such as distraction, relaxation/pleasure oriented, reappraisal, and social support.

When these strategies were sorted by participants it was found that the cognitive/behavioural and address/diversion distinctions were rated highly similar to the structure proposed by the researchers (Parkinson & Totterdell, 1999). Additionally, sub-clusters of affect recognition also had some degree of convergence with the model proposed by the authors. According to ratings from participants there was no evidence of situated- or affect-directed strategies, or active versus passive addressing, or diversion of the thoughts or feelings. However, there was some differentiation within the diversion category. The new distinction that was created within this factor regarded avoidance of versus distraction from negative mood states (Parkinson & Totterdell, 1999).

Parkinson and Totterdell's (1999) taxonomy of affect regulation provides a fairly comprehensive assessment of regulation strategies based both on a theoretical conceptualization of affect regulation and empirical evidence. Although their categorization does not provide information about the effectiveness of these strategies to regulate emotions, it offers a broader understanding of commonly used affect regulation strategies.

A meta-analysis by Augustine and Hemenover (2009) has attempted to provide some understanding of the effectiveness of various affect regulation strategies. Through their research they identify over 300 known ER strategies, which they categorized using Parkinson and Totterdell's (1999) taxonomy (as cited in Augustine & Hemenover, 2009, p. 1182). This taxonomy includes ER strategies that fit into categories such as, distraction, rumination, avoidance, suppression, reappraisal, catharsis and behavioural strategies. Studies examined found that cognitive reappraisal and distraction were the most effective ER strategies, whereas catharsis and expressive suppression were found to be ineffective (Augustine & Hemenover, 2009). This is consistent with work by Gross and John (2003) which has found that cognitive reappraisal has been associated with positive psychological outcomes, whereas expressive suppression has been linked with more negative outcomes.

Emotion regulation

A model of affect regulation that focuses upon the mechanisms of emotional change has been presented by Gross' (1998b) process model of ER. Herein, ER is defined as actively changing one's emotional experience towards an emotional goal (Gross, 1998b; Gross, 2015). This goal may refer to increasing, or decreasing the intensity of positive, or negative emotions and may be implemented either before, or after an emotion is felt. While it may seem counter-intuitive for individuals to need to decrease the intensity of positive emotions, there are situations where this would be useful based on cultural norms, such as suppressing feelings of happiness at a funeral (Gross, 2015).

Importantly, Gross (2015) makes a distinction between ER and conceptualizations of mood regulation and coping, such as those presented by Parkinson and Totterdell (1999), Thayer et al. (1994), and Skinner and colleagues (2003). According to Gross, these three regulatory processes are all categorized under the spectrum of affect regulation. Gross suggests that the activation of a goal to influence the magnitude of a felt emotion over time is what separates ER apart from mood regulation and coping. Although coping is similar to ER, Gross recognizes that coping focuses on the reduction of stress over longer periods of time. Similarly, mood regulation has significant overlap with ER, although moods are suggested by Gross (2015) to be more cognitively controlled and pervasive than emotions. Accordingly, mood regulation shares less with behavioural ER strategies, and more with cognitive ones. Both of these subtypes of ER are identified by Gross' (1998b) process model of ER and are further explained below.

According to Gross' (1998b) process model of emotion regulation, ER strategies deployed prior to feeling an emotion are referred to as antecedent-focused ER strategies, while those enacted after a felt emotion are referred to as response-focused ER strategies. Gross' process of ER consists of five components: (1) the selection of a situation; (2) the modification of problematic situations; (3) attentional deployment; (4) cognitive change; and (5) response modulation. The first four components lend themselves to antecedent-focused ER, while the fifth component is specific to response-focused ER (Gross, 1998b). Additionally, Gross (2015) identifies that emotions change from moment to moment and that we can have several different appraisals and responses to any given situation. The cyclical nature of emotional appraisal and regulation suggests that certain antecedent-focused ER strategies, such as cognitive change may not always be strictly antecedent and may at times be better considered as response-focused.

An example of an antecedent ER strategy at the level of selection of a situation would be to avoid going to a horror film, so that you do feel scared. Using the example of a horror film regarding the modification of problematic situations might involve bringing a friend with you for social support. A similar example, occurring at the attentional deployment level, would be averting your gaze just prior to seeing something terrifying in the film to reduce the negative feelings that you might have felt if you had continued to look at the screen. Cognitive change could entail you telling yourself that the film is not real, while response modulation might involve you not grimacing, or jumping out of your seat when something scary occurs. Selection of a situation, modification of the situation, attentional deployment, and response modulation are primarily ER strategies at the behavioural level. Conversely, as the name implies, cognitive change involves strategies at the cognitive level.

Through the process model described above, Gross and colleagues have often focused on two ER strategies, cognitive reappraisal, and expressive suppression. The reason for focusing on these two specific strategies was three-fold: to select commonly used strategies of ER, to identify strategies that could be manipulated and defined through individual differences, and to focus on the distinction between antecedent and response-focused ER strategies (Gross & John, 2003). Cognitive reappraisal is an example of cognitive change, while expressive suppression is an example of response modulation. The focus of the Emotion Regulation Questionnaire (ERQ), created by Gross and John (2003) was based on these two strategies. Accordingly, much of the research following its creation has also focused on understanding the use of these two ER strategies. Through this research, expressive suppression has been linked to several negative outcomes such as experience of more negative emotions, less positive emotions, poorer interpersonal functioning and greater psychological distress. Conversely, cognitive reappraisal has been linked to increased experience of positive emotions, reduced experience of negative emotions, better interpersonal functioning and improved well-being (Gross & John, 2003).

A meta-analysis by Webb and colleagues (Webb, Miles & Sheeran, 2012) also examined the effectiveness of ER strategies at each level of the process model proposed by James Gross

(1998b). Comparisons were analyzed at the level of attentional deployment, cognitive change, and response modulation (Webb et al., 2012). At the level of attentional deployment, strategies were either focused on distraction from, or concentration on the emotional experience. Regarding cognitive change, strategies were separated based on whether participants were instructed to reappraise the emotional stimulus, the emotional response, or to reappraise via perspective taking. Finally, distinctions were made at the level of response modulation based on whether the participants suppressed the expression, experience, or the thoughts associated with the emotion (Webb et al., 2012). Across studies, various emotional outcomes were measured. These involved experiential outcomes, which were typically measured through self-report, physiological outcomes, such as heart rate or EEG, and behavioural outcomes, typically measured through observer report of emotional expression (Webb et al., 2012). Overall, the authors found that cognitive change demonstrated a small to moderate effect size on emotional outcomes and was found to be significantly more effective on these outcomes than response modulation and attentional deployment. Additionally, response modulation was observed to have a small positive effect size on emotional outcomes and was significantly better than attentional deployment on these outcomes. Interestingly, when analysing differences within attentional deployment strategies, the authors found that distraction presented a small positive effect size, whereas concentration demonstrated a negative effect size to the same magnitude (Webb et al., 2012). This suggests that at the level of attentional deployment distraction may be an effective ER strategy, while concentration may represent an ineffective strategy. Regarding the effectiveness of response modulation, there was significant variability across different ER strategies within this category. Specifically, suppression of emotional expression was the only response modulation strategy that provided a small to moderate positive effect size. However, suppression of emotional experience and thoughts produced effect sizes close to zero. Thus it is unlikely that suppression of the emotion is an effective ER strategy. Moreover, this effect was almost entirely driven by behavioural measures and there were almost no effects regarding self-report and physiological measures (Webb et al., 2012). This is consistent with research by Gross and John (2003) and Augustine and Hemenover (2009) which identifies expressive suppression as an ineffective ER strategy. Regarding cognitive change, all forms of reappraisal presented small to moderate positive effect sizes; however, reappraisal through perspective taking was significantly more effective than reappraisal of the emotional response. This is also consistent with recent research categorizing cognitive reappraisal as an effective ER strategy (Augustine & Hemenover, 2009; Gross & John, 2003).

Several models of affect regulation have been developed over the past 20 years. Generally, ER is considered to be both similar to and different from mood regulation and coping. However, all of these models have considered affect regulation to relate to changing felt emotions towards some emotional goal whether it be long-term or more immediate. Overall, James Gross' (1998b) process model of ER has gained the most traction in the literature, and a plethora of research has been devoted to investigating the effectiveness of expressive suppression and cognitive reappraisal in the regulation of emotions. Accordingly, we take the perspective of this model when defining emotion regulation.

2.2 Development of ER and related faculties

Now that we have an understanding of what ER is, it is important that we consider how ER processes develop, and how they are distinguished from other emotional processes. A review article by Thompson (2011) makes sense of emotional development from a systems perspective.

From this perspective influences from many facets of emotional processing, such as sensory, socio-cultural, cognitive and environmental effects, are considered (Thompson, 2011).

In infancy, regulation of emotions consists of expressing distress to gain the attention of one's parents (Thompson, 2011). More intermediate ER strategies, coinciding with the development of theory of mind, might include becoming overtly frustrated with another child for blocking your goal (Thompson, 2011). These earlier ER strategies are focused primarily on regulating emotions through external sources. More internal regulation strategies begin to develop when children start to understand culturally acceptable norms for expressing and experiencing emotions (Thompson, 2011). For example, children in western cultures may count to ten to avoid physically attacking another child for making fun of them, as this is typically not considered an appropriate response. Appraisals of emotions and associated regulation of these emotions becomes increasingly influenced by socio-cultural norms, and environmental experiences. Regulation of emotions also becomes more considerate of long-term emotional goals as children develop the ability to plan and monitor their goals over a longer period of time (Thompson, 2011).

According to Thompson (2011), early regulation strategies develop through the acquisition of more acute attentional control, which may influence emotional appraisals. Thus, infants may more effectively satisfy internal emotional goals, such as distress caused by hunger, through recognizing that their caregiver is present, and through crying to get their attention. Once a cursory understanding of language has been achieved, Thompson (2011) suggests that ER develops primarily as a result of internal schemata created through parent-child interactions. These interactions communicate expectations of appropriate expression and experience of emotions. Early interactions between the child and parents are typically the first of their kind and set the stage for beliefs about emotions, emotional expression and its consequences, and others' representation of emotions (Thompson, 2011).

The influence of the child-parent interaction on normative ER development is supported by a review by Southam-Gerow and Kendall (2002). This review points out that these interactions are affected by childhood temperament, attachment, and parenting style. Importantly, both developmental reviews highlight the importance of the development of healthy ER strategies for later interpersonal and intrapersonal functioning (Southam-Gerow & Kendall, 2002; Thompson, 2011). Moreover, Thompson (2011) identifies that negative early parent-child interactions quickly foster regulation strategies that may be adaptive given the child's environment and may serve the purpose of meeting their short-term emotional goals; however, these strategies may become detrimental long-term strategies and may also be ineffective when generalized to other environments or situations. It can be very difficult for these strategies to be modified or overridden once they have been developed, which can then lead to difficulties with mental health and socio-emotional aptitude (Southam-Gerow & Kendall, 2002).

Another influence identified as an important factor in the development of ER is emotional understanding (Southam-Gerow & Kendall, 2002). According to Southam-Gerow and Kendall (2002) emotional understanding involves knowledge about their own and others' emotions including causes of, and cues for emotions, as well as methods of communicating emotions through expression, and coping with their own emotions. These methods of expressing and coping with emotions refer not to the active management of emotions, but rather the knowledge of the ability that emotions can be managed (Southam-Gerow & Kendall, 2002). Considering that ER involves the active management of emotions, it is necessary for an individual to be able to identify the emotion to be regulated, and as such emotional understanding is a fundamental aspect of ER.

Another aspect of emotion that may affect the development of ER has been referred to as emotional sensitivity or reactivity. Koole (2009) refers to emotional reactivity as emotional information that has not had a chance to be cognitively processed. Thus sensitivity refers to emotional information that has not yet been controlled or manipulated by the individual (Koole, 2009). As identified by Davidson (1998), it is often not clear where an emotion ends and regulation begins (As cited in Koole, 2009, p. 8). Of course, this could be considered as a failure to suppress this emotional information. However, an individual must be able to both identify that they are having an emotion, and be able to identify which emotion they are having, in order to effectively regulate that emotion (Koole, 2009; Southam-Gerow & Kendall, 2002). According to Koole, this primary emotional response has been referred to as emotional sensitivity and it is quickly followed by a secondary emotional response which is the regulation of the primary emotional reaction. Regarding emotional sensitivity, individuals may differ in the intensity of their primary emotional response, which may have implications for the development of adaptive ER strategies and the ability to effectively down-regulate more intense emotions.

A developmental study by Silvers and colleagues (Silvers, McRae, Gabrieli, Gross, Remy & Ochsner, 2012) examined differences in both regulation and reactivity in children, adolescents and young adults aged 10-22. They found that ER success, operationalized by successful cognitive reappraisal of an emotion, increased significantly until 16 years-of-age, whereas there was no significant relationship between emotional reactivity and age. Interestingly, the developmental trajectory of regulation success is similar to the developmental course of executive functions. Specifically, these findings suggest cognitive reappraisal success, working memory and shifting ability all continue to develop into mid-adolescence (Huizinga et al., 2006; Lehto et al., 2003; Silvers et al., 2012).

Additionally, the finding that reactivity does not demonstrate a linear relationship with age suggests that reactivity has either fully developed by 10 years-of-age, or that it is relatively stable from birth. Indeed, longitudinal research from infancy to four years had demonstrated that reactivity is fairly robust and may be present and stable from birth (Ursache, Blair, Stifter & Voegtline, 2013). This latter study also suggests that there is a relationship between ER success and reactivity, which is mediated by positive parent-child interactions. As identified by Southam-Gerow and Kendall (2002), and Thompson (2012) the parent-child relationship is vital to the development of healthy ER. Research by Ursache and colleagues suggests that reactivity may also play an important role in the acquisition of adaptive ER strategies. It is unclear from the Silvers and colleagues (2012) study whether or not reactivity influences the ability to successfully reappraise an emotion. Although no comparisons were reported regarding the association of these two concepts in the Silvers study, there is some indication, through more recent research, that reactivity is a relatively stable trait. Accordingly, further research is necessary to determine the nature of the relationship between ER and emotional reactivity.

Nonetheless, the distinction between reactivity and regulation does have some supporting research (Koole, 2009, Ursache et al., 2013). Reactivity involves a primary emotional response and the realization that an individual is having an emotion, which is followed by regulation, a secondary emotional response involving some form of cognitive control of that emotion to either increase or decrease its valence (Koole, 2009). It is thought that reactivity and regulation interact, and that the development of regulation may be influenced by reactivity although very few studies have carefully examined this interaction (Koole, 2009; Silvers et al., 2012; Ursache et al., 2013).

3. Interplay of EF and ER

ER and EF both involve the ability to regulate one's thoughts/emotions/behaviours in the pursuit of a goal. Although conceptual similarities between EF and ER exist, there is a dearth of research examining how these constructs may be associated. Nonetheless, there are a considerable amount of studies examining the neuroanatomical networks of EF and ER independently, and these studies have observed some overlap in function between these two processes. Additionally, a few research studies have examined the relationship between EF and ER directly using behavioural measures and found some association between EF and ER. Furthermore, studies examining dysfunctional EF and ER have found other common correlates, such as mental health concerns. These studies and their contribution to the literature will be described in the following sections.

3.1 Neuroanatomical substrates of EF and ER

EF and ER are both supported by neuroanatomical networks in which pre-frontal brain regions play an important role. Regarding neuroanatomical networks of ER, an fMRI study by Ochsner and colleagues (2002) identified increased activation of left lateralized frontal areas involved in active reappraisal of negative emotions. Specifically, they reported increased activation of the left lateralized medial orbitofrontal cortex, ventro- and dorsolateral prefrontal cortices, and the ACC, as well as decreases in amygdala activation during reappraisal of negative emotions. A more recent review paper by Ochsner and Gross (2005) presents additional evidence supporting the involvement of these frontal brain regions in the use of emotion regulation strategies.

When considering neuroanatomical networks of EF, a meta-analysis of fMRI studies examining neural activity during various EF tasks revealed findings similar to that of ER research (Houde et al., 2010). Overall, studies demonstrated that both children and adolescents utilized bilateral frontal areas including the dorsolateral and inferior prefrontal cortices, and the insular cortex. Houde and colleagues (2010) did identify a minor difference between adolescents and children, which was that insular activation shifted from being left lateralized in childhood to right lateralized in adolescence. Nonetheless, the areas involved during EF tasks seem to remain largely analogous throughout development.

In addition to the aforementioned areas being involved in EF, a review paper by Bellebaum and Daum (2007) has identified the cerebellum as an area of importance with regard to working memory specifically. Although the involvement of the cerebellum seems to be less important than the PFC for carrying out executive tasks, it should not be overlooked when considering neural networks of EF. Moreover, it should be noted that no known research study has found a relationship between emotion regulation and cerebellar activity.

Overall, EF and ER neural networks seem to share common areas including the dorso- and ventro-lateral PFC and the ACC. Emotion regulation seems to involve orbitofrontal areas more so than EF. Conversely, EF seems to involve the cerebellum and parietal areas to a greater degree than ER. Compared to other areas of the brain, these frontal areas develop slowly and are typically not fully matured until the 2^{nd} decade of life. Given that ER and EF share these common neural substrates, it is not surprising that the development of internally controlled ER and effective EF lag behind the development of other abilities, such as visual and motor skills.

3.2 Behavioural studies of EF and ER

A developmental study by Carlson and Wang (2007) examined similarities between inhibitory control and emotion regulation. They did so through behavioural and parent-report measures that looked primarily at inhibition and expressive suppression in a sample of 4- and 5-year-olds. The researchers found that a composite of emotion regulation, consisting of two expressive suppression tasks and an emotional understanding task, and a composite of inhibitory control, consisting of three inhibitory tasks were significantly positively correlated with each other, and that all behavioural measures loaded onto a single factor which accounted for 58% of the variance. Furthermore, parent-report measures of both emotion regulation and inhibitory control were significantly correlated with each other and with behavioural composites of these constructs (Carlson & Wang, 2007). Interestingly, the authors found effects of both gender and age. The aforementioned effects were only present for females and when collapsed across gender and only remained significant for 4-year-olds (Carlson & Wang, 2007). One explanation for this pattern of results could be that the between-groups factors had relatively small *n*'s and as such did not reach significance based on this limitation, although effect sizes of these groups were still below 0.1 (Carlson & Wang, 2007). Overall, these results suggest some promising relationships between expressive suppression and inhibitory control in a developing population. It is unclear whether aspects of ER and EF overlap in their development, such that some overarching self-regulatory process may be driving the two, or whether ER plays a primary role in the development of EF, or vice-versa (Carlson & Wang, 2007). Given the modest effect sizes found, it is assumed that these two processes are separable self-regulatory abilities. Longitudinal research determining the developmental trajectory of these functions would help define the directionality of these relationships.

More recently, longitudinal research examining the interplay of EF and ER has been carried out by Ursache and colleagues (Ursache, Blair, Stifter & Voegtline, 2013). These researchers assessed ER and emotional reactivity in infancy, and evaluated EF at age four. They exposed infants to fear evoking stimuli while they were with their parents, and coded the infants' facial expressions from moment to moment in order to assess their reactivity and ability to regulate their emotions. This was done at 7-, 15-, and 24-months of age. Children were given a battery of six behavioural measures assessing executive functioning at 48-months of age. Three of the measures assessed inhibition, two measured working memory and one assessed shifting ability (Ursache et al., 2013). Results indicated that neither regulation nor reactivity at any of the three time-points predicted EF at 48 months; however, there was a significant regulation by reactivity interaction at 15 months (Ursache et al., 2013). Further analysis indicated that high reactivity and more positive regulation abilities predicted higher levels of EF at 48 months, while high reactivity and poorer regulation abilities produced poorer executive abilities at 48 months. This suggests that the relationship between EF and early ER is moderated by reactivity. Furthermore, the researchers found that positive parenting practices mediated the effect of reactivity on EF, such that children who were more reactive and demonstrated higher executive abilities also had parents who offered more support to their child during the fear evoking situations (Ursache et al., 2013). The authors suggest that this external regulation of emotions through the parents may lead to lower physiological arousal, which may subsequently free up cognitive resources conducive to fostering positive executive abilities (Ursache et al., 2013). Additionally, this external regulation may also allow for similar mechanisms to promote the development of adaptive self-regulated ER abilities. Although the researchers' analyses only found this pattern of results at 15-months of age, it still provides some empirical evidence of a complex relationship between ER and EF at an early stage of development.

The prior studies have specifically examined the relationship of EF and ER in young children and infants. It has been established that at these young ages both of these abilities are still undergoing changes and that they do not fully mature until later in development (Best & Miller, 2010; Huzinga et al., 2006; Koole, 2009; Lehto et al., 2003; Silvers et al., 2012; Southam-Gerow & Kendall, 2002; Thompson, 2011; Van der Ven, 2012). A study by Bridgett and colleagues (Bridgett, Oddi, Laake, Murdock & Bachmann, 2013) assessed whether these constructs were associated with each other in a sample of adults. This was done through the use of several behavioural measures to assess executive abilities and self-report questionnaires to measure the expression and experience of negative affect. Overall, the researchers found that inhibition was specifically related to the expression of negative affect, but not the experience of negative affect, while working memory was related to the experience of negative affect, but not the expression of negative affect (Bridgett et al., 2013). The authors suggest that this indicates that inhibition may be related to regulation of the overt expression of emotions similar to the ER strategy of expressive suppression. These findings would be consistent with Carlson and Wang's (2007) findings in young children. Additionally, Bridgett and colleagues propose that working memory may be related to the regulatory abilities that include altering the experience of emotions, such as cognitive reappraisal (Bridgett et al., 2013). Unfortunately, the researchers did not overtly measure whether these findings were related to increased use of expressive suppression or cognitive reappraisal through well-validated measures such as the ERQ (Gross & John, 2003). Accordingly, it is impossible to know whether this hypothesis would be supported empirically. Nonetheless, this research provides some foundation for future research to build upon.

Other studies have looked at the relationship between EF and ER in samples of neurologically abnormal individuals. A study by Gyurak and colleagues (Gyurak, Goodkind, Kramer, Miller & Levenson, 2012) assessed abilities to down- and up-regulate both positive and negative emotions while watching a movie clip. Their sample included older adults with and without a diagnosis of a neurodegenerative disorder. Heart rate was recorded during the ER task. The researchers evaluated the participants EF abilities through four tasks. A single task was used to examine inhibition, working memory, switching and verbal fluency (Gyurak et al., 2012). Results indicated that ER ability was significantly related to measures of verbal fluency, but not to other measures of EF. The researchers propose that verbal fluency requires more complex planning and monitoring abilities than the other executive abilities measured, and accordingly may therefore be used more when regulating one's emotions (Gyurak et al., 2012). Interestingly, comparisons between those with and without a neurodegenerative disorder were not carried out in this study. Rather, participants with a neurodegenerative disorder were included to provide a wide range of executive function capabilities (Gyurak et al., 2012). However, the degree to which the findings were driven by the abnormal individuals was not reported. Accordingly, this study provides some evidence that verbal fluency is related to successful up- and down-regulation of emotions across a spectrum of older adults. Unfortunately, these findings did not generalize to any of the core EF constructs.

Another study conducted by Phillips and colleagues (Phillips, Henry, Nouzova, Cooper, Radlak & Summers, 2014) compared the relationship of EF and ER between a group of individuals with a diagnosis of Multiple Sclerosis (MS) and healthy controls. The researchers evaluated ER, anxiety and depressive symptoms and quality of life through self-report questionnaires. Executive abilities, specifically sustained attention ability and verbal fluency, were measured using behavioural tasks (Phillips et al., 2014). Overall, they found that individuals with a diagnosis of MS scored significantly worse on all measures, and that within this group, emotion regulation ability was significantly related to verbal fluency (Phillips et al., 2014). This provides further evidence that ER is related to verbal fluency and supports research findings by Gyurak and colleagues (2012), who found similar results in a mixed sample of older adults with and without a neurodegenerative disorder.

Across the aforementioned studies there is some indication that aspects of EF and ER share some commonality. Unfortunately, the most compelling evidence comes from research with young children, and as mentioned, both ER and EF are not fully developed at these times (Huizinga et al., 2006; Lehto et al., 2003; Van der Ven et al., 2013). Accordingly, it is difficult to draw much from these studies. The other area where there is decent empirical data supporting a connection between ER and EF is in individuals who have a diagnosis of a neurological disorder (Gyurak et al., 2012; Phillips et al., 2014). Unfortunately, neither of these studies found a connection between ER, inhibition, working memory, or shifting. Nonetheless, the finding that ER and measures of verbal fluency are associated is still interesting. However, it does not provide conclusive evidence that EF and ER are indeed related. The study by Bridgett and colleagues (2013) does offer some hope in providing an indication that these concepts are related in typically developing young adults, although their operationalization of ER was inadequate to provide any confirmation of the relationship between ER and EF. Taken together, it is clear that these findings are quite inconclusive and future research is needed to determine whether an association between ER and EF truly exists.

3.3 EF, ER and mental health

In addition to the previous two studies identifying difficulties with EF and ER in atypical populations, several studies have considered difficulties with EF and ER in the development and maintenance of various mental health concerns. Dysfunctional EF has been commonly linked to attention deficit hyperactivity disorder (ADHD; Barkley, 1997; Lipszyc & Schachar, 2010), major depressive disorder (MDD; Ikeda, Shiozaki, Ikeda, Suzuki & Hirayasu, 2013; Wingo, Kalkut, Tuminello, Asconape & Han, 2013), anorexia nervosa (Gillberg, Billstedt, Wentz, Anckarsater, Rastam & Gillberg, 2010), elevated state and trait anxiety (Visu-Petra, Miclea & Visu-Petra, 2013) and substance abuse (Wilens et al., 2011). Similarly, difficulty regulating one's emotions has been associated with ADHD (Melnick & Hinshaw, 2000), oppositional defiant disorder (ODD; Fraire & Ollendick, 2011) MDD (Aldao & Nolen-Hoeksema, 2010), generalized anxiety disorder (GAD; Campbell-Sills, Simmons, Lovero, Rochlin Paulus & Stein, 2011), substance abuse, specific phobias, bipolar disorder (Gruber, Eidelman & Harvey, 2008) eating disorders, borderline personality disorder (Svaldi, Griepenstroh, Tuschen-Caffier & Ehring, 2012), and posttraumatic stress disorder (PTSD; Fairholme, Nosen, Nillni, Schumacher, Tull & Coffey, 2013). This provides strong evidence that difficulties with both EF and ER are often related to mental health problems, and that there is a great deal of overlap in the presentation of mental health difficulties. It is, however, unclear as to whether these mental health issues are caused by difficulties with EF and ER, or whether these mental health issues may cause difficulties with EF and ER. Nonetheless, dysfunctional EF and ER seem to both co-occur with a wide variety of mental health concerns.

Through the aforementioned research, it is clear that EF and ER share common neural correlates, and that they are implicated in similar types of mental health difficulties. Additionally, a few behavioural studies have demonstrated some direct association between aspects of EF and ER. However, very few research studies have looked at this association and it is unclear exactly how these processes are similar, and whether or not they are related throughout development and into adulthood. Future research should aim to capture the precise nature of the interaction between these two processes in a well-controlled study.

Introduction

In the current study we explore how executive functions (EF) and emotion regulation (ER) are related. Both EF and ER are self-regulatory abilities which have been linked to common mental health outcomes; however, few research studies have looked at the direct relationship or considered common underlying factors that may influence this relationship. The current study examined the relationships between ER strategy use, EFs, and their joint and independent effects on the experience of emotions and psychological distress. Additionally, emotional reactivity was evaluated as a moderator of the relationship between EF, ER and the experience of emotions and psychological distress.

Executive functions

Executive functions (EF) are typically viewed as processes used to self-regulate one's thoughts and behaviours towards a goal (Alvarez & Emory, 2006). According to Miyake and colleagues' (2000) unity and diversity framework, EF is composed of a set of interrelated, but separable constructs that aid individuals in the effortful self-regulation of their thoughts and actions towards a specific goal. The three major factors that Miyake and colleagues (2000) have focused on are inhibition of prepotent responses, updating and monitoring of working memory representations, and shifting between task demands. Inhibition refers to the deliberate process of stopping oneself from performing a prepotent response. Updating includes actively updating, monitoring and coding task-relevant information. Shifting is the ability to switch attention between tasks or mental sets, which requires individuals to disengage from an irrelevant task or mental set in order to engage in a relevant task or mental set. These three executive skills were focused on because they have been well studied, are viewed as being more central to the executive construct, and relatedly, are thought to be required for more complex forms of EF

(Miyake et al., 2000). Confirmatory factor analysis by Miyake and colleagues has largely supported this conceptualization of EF, and although other models of EF have been proposed (Baddeley & Hitch, 1974; Nigg, 2000; Munakata, Snyder and Chatam, 2012; Norman & Shallice, 1974; Posner & Boies, 1971; Zelazo & Frye 1998), Miyake et al.'s EF structure has gained the most support in the literature. Therefore, we have adopted the unity and diversity framework of EF when conceptualizing EF.

Emotion regulation

Another self-regulatory ability, emotion regulation (ER), has been a topic of increasing interest over the past 20 years. Over this time, various conceptualizations of what ER entails have been put forth. Typically these models share the idea that ER involves the active management of emotions in pursuit of an emotional goal (Gross, 1998b; Koole, 2009; Parkinson & Totterdell, 1999; Southam-Gerow & Kendall, 2002; Thayer Newman & McClain, 1994; Thompson, 1994; Thompson, 2011). In this way, ER is generally similar to EF in the sense that it requires an individual to monitor internal and external information, and apply changes towards a desired goal. Also like EF, ER has several similar models defining what it entails.

A model of affect regulation that focuses upon the mechanisms of emotional change has been presented by Gross' (1998b) process model of ER. Herein, ER is defined as actively changing one's emotional experience towards an emotional goal (Gross, 1998b; Gross, 2015). This goal may refer to increasing, or decreasing the intensity of positive, or negative emotions and may be implemented either before, or after an emotion is felt. While it may seem counter-intuitive for individuals to need to decrease the intensity of positive emotions, there are situations where this would be useful based on cultural norms, such as suppressing feelings of happiness at a funeral (Gross, 2015).

According to Gross' (1998b) process model of emotion regulation, ER strategies deployed prior to feeling an emotion are referred to as antecedent-focused ER strategies, while those enacted after a felt emotion are referred to as response-focused ER strategies. Gross' process of ER consists of five components: (1) the selection of a situation; (2) the modification of problematic situations; (3) attentional deployment; (4) cognitive change; and (5) response modulation. The first four components lend themselves to antecedent-focused ER, while the fifth component is specific to response-focused ER (Gross, 1998b). Additionally, Gross (2015) identifies that emotions change from moment to moment and that we can have several different appraisals and responses to any given situation. The cyclical nature of emotional appraisal and regulation suggests that certain antecedent-focused ER strategies, such as cognitive change may not always be strictly antecedent and may at times be better considered as response-focused.

Through the process model described above, Gross and colleagues have often focused on two ER strategies, cognitive reappraisal, and expressive suppression. The reason for focusing on these two specific strategies was three-fold: to select commonly used strategies of ER, to identify strategies that could be manipulated and defined through individual differences, and to focus on the distinction between antecedent and response-focused ER strategies (Gross & John, 2003).

Cognitive reappraisal is an exemplar strategy of an antecedent ER strategy at the level of cognitive change. An example of cognitive reappraisal could entail you telling yourself that the events portrayed in a horror film are not real. Conversely, expressive suppression is an example of a response-focused ER strategy at the level of response modulation. An example of expressive suppression might involve you not grimacing, or jumping out of your seat when something scary occurs. Response modulation is an ER strategy utilized at the behavioural level, while as the name implies, cognitive reappraisal involves strategies deployed at the cognitive level.

Similar to conceptualizations of EF, several models of ER have been proposed (Koole, 2009; Parkinson & Totterdell, 1999; Thayer Newman & McClain, 1994). However, James Gross' (1998b) process model of ER has gained the most traction in the literature, and a plethora of research has been devoted to investigating the effectiveness of expressive suppression and cognitive reappraisal in the regulation of emotions. Accordingly, we take the perspective of this model when defining emotion regulation.

Emotional reactivity

An aspect of emotion that may affect the ability to successfully enact various ER strategies has been referred to as emotional reactivity. Koole (2009) refers to emotional reactivity as emotional information that has not had a chance to be cognitively processed. Thus reactivity refers to emotional information that has not yet been controlled or manipulated by the individual (Koole, 2009). As identified by Davidson (1998), it is often not clear where an emotion ends and regulation begins (As cited in Koole, 2009, p. 8). According to Koole, this primary emotional response has been referred to as emotional reactivity and it is quickly followed by a secondary emotional response which is the regulation of the primary emotional reaction. Regarding emotional reactivity, individuals may differ in the intensity of their primary emotional response, which may have implications for the successful use of adaptive ER strategies and the ability to effectively down-regulate more intense emotions.

EF, ER and psychological distress

ER and EF both involve the ability to regulate one's thoughts/emotions/behaviours in the pursuit of a goal. Although conceptual similarities between EF and ER exist, there is a dearth of research examining how these constructs may be associated. Nonetheless, a few research studies have examined the relationship between EF and ER directly using behavioural measures and found some association between EF and ER. Furthermore, studies examining dysfunctional EF and ER have found other common correlates, such as mental health concerns. The following section reviews these studies and their contribution to the literature.

A developmental study by Carlson and Wang (2007) examined similarities between inhibitory control and emotion regulation. They did so through behavioural and parent-report measures that looked primarily at inhibition and expressive suppression in a sample of 4- and 5-year-olds. The researchers found that a composite of emotion regulation, consisting of two expressive suppression tasks and an emotional understanding task, and a composite of inhibitory control, consisting of three inhibitory tasks were significantly positively correlated with each other, and that all behavioural measures loaded onto a single factor which accounted for 58% of the variance. Furthermore, parent-report measures of both emotion regulation and inhibitory control were significantly correlated with each other and with behavioural composites of these constructs (Carlson & Wang, 2007). Overall, these results suggest some promising relationships between expressive suppression and inhibitory control in a developing population. It is unclear whether these effects would generalize to more mature samples.

More recently, longitudinal research examining the interplay of EF and ER has been carried out by Ursache and colleagues (Ursache, Blair, Stifter & Voegtline, 2013). These researchers assessed ER and emotional reactivity in infancy, and then evaluated EF at age four. They exposed infants to fear evoking stimuli while they were with their parents, and coded the infants' facial expressions from moment to moment in order to assess their reactivity and ability to regulate their emotions. This was done at 7-, 15-, and 24-months of age. Children were given a battery of six behavioural measures assessing executive functioning at 48-months of age. Three of the measures assessed inhibition, two measured working memory and one assessed shifting ability (Ursache et al., 2013). Results indicated that neither regulation nor reactivity at any of the three time-points predicted EF at 48 months; however, there was a significant regulation by reactivity interaction at 15 months (Ursache et al., 2013). Further analysis indicated that high reactivity and more positive regulation abilities predicted higher levels of EF at 48 months, while high reactivity and poorer regulation abilities produced poorer executive abilities at 48 months. This suggests that early reactivity is moderated by the ability to regulate emotions in an adaptive way. Furthermore, the researchers found that positive parenting practices mediated the effect of reactivity on EF, such that children who were more reactive and demonstrated higher executive abilities also had parents who offered more support to their child during the fear evoking situations (Ursache et al., 2013). The authors suggest that this external regulation of emotions through the parents may lead to lower physiological arousal, which may subsequently free up cognitive resources conducive to fostering positive executive abilities (Ursache et al., 2013). Again it is unclear how these results would generalize to more mature samples. However, these results suggest an interaction of ER and emotional reactivity in the prediction of executive abilities.

A study by Bridgett and colleagues (Bridgett, Oddi, Laake, Murdock & Bachmann, 2013) assessed whether these constructs were associated with each other in a sample of adults. This was done through the use of several behavioural measures to assess executive abilities and self-report questionnaires to measure the expression and experience of negative affect. Overall, the researchers found that inhibition was specifically related to the expression of negative affect, but not the experience of negative affect, while working memory was related to the experience of negative affect, but not the expression of negative affect (Bridgett et al., 2013). The authors suggest that this indicates that inhibition may be related to regulation of the overt expression of emotions similar to the ER strategy of expressive suppression. Additionally, Bridgett and colleagues propose that working memory may be related to the regulatory abilities that include altering the experience of emotions, such as cognitive reappraisal (Bridgett et al., 2013). Unfortunately, the researchers did not overtly measure whether these findings were related to increased use of expressive suppression or cognitive reappraisal through well-validated measures such as the ERQ (Gross & John, 2003). Accordingly, it is impossible to know whether this hypothesis would be supported empirically. Nonetheless, this research provides some theoretical foundation for future research to build upon.

A study by Gyurak and colleagues (Gyurak, Goodkind, Kramer, Miller & Levenson, 2012) assessed abilities to down- and up-regulate both positive and negative emotions while watching a movie clip. Their sample included older adults with and without a diagnosis of a neurodegenerative disorder. Heart rate was recorded during the ER task. The researchers evaluated the participants EF abilities through four tasks. A single task was used to examine inhibition, working memory, switching and verbal fluency (Gyurak et al., 2012). Results indicated that ER ability was significantly related to measures of verbal fluency, but not to other measures of EF. The researchers propose that verbal fluency requires more complex planning and monitoring abilities than the other executive abilities measured, and accordingly may therefore be used more when regulating one’s emotions (Gyurak et al., 2012). This study provides some evidence that verbal fluency is related to successful up- and down-regulation of emotions across a spectrum of older adults. Unfortunately, these findings did not generalize to any of the core EF constructs.

Another study conducted by Phillips and colleagues (Phillips, Henry, Nouzova, Cooper, Radlak & Summers, 2014) compared the relationship of EF and ER between a group of individuals with a diagnosis of Multiple Sclerosis (MS) and healthy controls. The researchers evaluated ER, anxiety and depressive symptoms and quality of life through self-report questionnaires. Executive abilities, specifically sustained attention ability and verbal fluency, were measured using behavioural tasks (Phillips et al., 2014). Overall, they found that individuals with a diagnosis of MS scored significantly worse on all measures, and that within this group, emotion regulation ability was significantly related to verbal fluency (Phillips et al., 2014). This provides further evidence that ER is related to verbal fluency and supports research findings by Gyurak and colleagues (2012), who found similar results in a mixed sample of older adults with and without a neurodegenerative disorder.

Across the aforementioned studies there is some indication that aspects of EF and ER share some commonality. Unfortunately, the most compelling evidence comes from research with young children. The other area where there is decent empirical data supporting a connection between ER and EF is in individuals who have a diagnosis of a neurological disorder. The study by Bridgett and colleagues (2013) does offer some hope in providing an indication that these concepts are related in typically developing young adults, although their operationalization of ER was inadequate to provide any confirmation of the relationship between ER and EF. Taken together, it is clear that these findings are quite inconclusive and future research is needed to determine whether an association between ER and EF truly exists.

Through research on the Emotion Regulation Questionnaire (ERQ; Gross & John, 2003), expressive suppression has been linked to several negative outcomes such as experience of more negative emotions, less positive emotions, poorer interpersonal functioning and greater psychological distress. Conversely, cognitive reappraisal has been linked to increased experience of positive emotions, reduced experience of negative emotions, better interpersonal functioning and improved well-being (Gross & John, 2003). Several other studies have considered difficulties with EF and ER in the development and maintenance of various mental health concerns. Dysfunctional EF has been commonly linked to attention deficit hyperactivity disorder (ADHD; Barkley, 1997; Lipszyc & Schachar, 2010), major depressive disorder (MDD; Ikeda, Shiozaki, Ikeda, Suzuki & Hirayasu, 2013; Wingo, Kalkut, Tuminello, Asconape & Han, 2013), anorexia nervosa (Gillberg, Billstedt, Wentz, Anckarsater, Rastam & Gillberg, 2010), elevated state and trait anxiety (Visu-Petra, Miclea & Visu-Petra, 2013) and substance abuse (Wilens et al., 2011). Similarly, difficulties regulating one's emotions has been associated with ADHD (Melnick & Hinshaw, 2000), oppositional defiant disorder (ODD; Fraire & Ollendick, 2011) MDD (Aldao & Nolen-Hoeksema, 2010), generalized anxiety disorder (GAD; Campbell-Sills, Simmons, Lovero, Rochlin Paulus & Stein, 2011), substance abuse, specific phobias, bipolar disorder (Gruber, Eidelman & Harvey, 2008) eating disorders, borderline personality disorder (Svaldi, Griepenstroh, Tuschen-Caffier & Ehring, 2012), and posttraumatic stress disorder (PTSD; Fairholme, Nosen, Nillni, Schumacher, Tull & Coffey, 2013). This provides strong evidence that difficulties with both EF and ER are often related to mental health problems, and that there is a great deal of overlap in the presentation of mental health difficulties. It is, however, unclear as to whether these mental health issues are caused by difficulties with EF and ER, or whether these mental health issues may cause difficulties with EF and ER. Nonetheless, dysfunctional EF and ER seem to both co-occur with a wide variety of mental health concerns.

Purpose of the present study

EF and ER share the function of self-regulation towards a goal. Additionally, difficulties with either of these abilities have been linked to a plethora of mental health difficulties. Furthermore, emotional reactivity has been suggested to be theoretically related to the successful use of various ER strategies. As of yet, however, very few research studies have examined the joint association of these two processes, or looked at factors, such as emotional reactivity, that might moderate this relationship. Accordingly, the current study aims to assess the degree to which EF and ER are related, replicate findings that implicate difficulties with these processes and mental health difficulties, and to examine emotional reactivity as a potential moderator of the relationship between EF, ER and mental health difficulties. Primarily, we are interested in how emotional reactivity will interact with EF and ER as predictors of mental health and emotional outcomes.

In the current study, we expect that performance on EF tasks will be related to reported ER strategies. Specifically, we want to test the idea proposed by Bridgett and colleagues (2013) that cognitive reappraisal will be related to working memory, while expressive suppression will be related to inhibitory ability. We further predict that EF and ER strategies will be related to emotional experience and psychological well-being. Herein, we expect to replicate findings by John and Gross (2003) that relates cognitive reappraisal to more positive outcomes and less negative ones, and expressive suppression with more negative outcomes and less positive ones. Additionally, we predict that weak working memory and inhibitory ability will be associated with more psychological distress, and that, similar to Bridgett and colleagues (2013) findings, working memory will be related to less negative affect. Finally, based on results from Ursache and colleagues (2013) we predict that there will be an interaction between emotion regulation and emotional reactivity in predicting emotional outcomes such that those with high emotional reactivity and high cognitive reappraisal, or low expressive suppression will report more adaptive emotional outcomes. Because we are not conducting a longitudinal study, indices of EF will not be entered as outcome variables. Accordingly, it is difficult to say what effect, if any EF will have on the relationship between reactivity and emotion regulation in predicting the experience of affect and psychological distress.

Methods

*Participants and procedure***.** 96 undergraduate students from the University of Waterloo participated in this study (Mean age = 20 years, 65% female, 77% native English speakers). Data were missing from 7 participants due to researcher error or technical issues. Data were excluded for 3 participants due to excessive errors. Data from 86 participants were entered into the analyses. Participants completed tasks in a single 90-minute session in the following order: Letter-number Sequencing, Flanker task, Positive and Negative Affect Schedule (PANAS), Automated Reading Span, Emotion Regulation Questionnaire (ERQ), Stop Signal task, Emotion Reactivity Scale (ERS), Automated Operation Span, Brief Symptom Inventory (BSI), Spatial Compatibility task, and a background questionnaire. Recruitment took place through a departmental pool of undergraduate students enrolled in psychology courses who participated for course credit.

Measures

Working Memory Tasks

Letter-number Sequencing. This is an adaptation of the Letter-number Sequencing subtest of the WAIS-IV (Pearson, 2008), and requires the participant to repeat mixed up strings of letters and numbers of increasing length. Participants listened to an audio recording of the strings of numbers and letters and repeated them back to the experimenter stating with the numbers first in order, followed by the letters in alphabetical order. Letter-number strings were presented in blocks of three. After each block of three items, another letter or number was added to the sequence. Sequences ranged from two to nine letter-number combinations. If the participant failed to correctly repeat all three items in a block the task was discontinued. A total score is derived by summing the number of correctly recalled trials. Scores can range from 0 to 30. The letter-number sequencing task has good internal consistency (α = .90; Pearson, 2008).

Reading Span and Operation Span. These are automated versions of the Reading and Operation Span tasks (Unsworth, Heitz, Schrock & Engle, 2005). In each task, participants are required to hold a string of letters in mind while they are concurrently asked to evaluate either math or reading problems presented to them in between each letter stimulus. In operation span participants are asked to evaluate simple math problems, while in reading span participants are required to figure out whether short sentences make logical sense. Participants are instructed to provide answers to the sentences or operations as quickly as possible while trying to keep their answers as accurate as possible. They are instructed to try to maintain 85% accuracy throughout the task. Their percentage correct responses is presented after every trial. These tasks present a total of 75 letters to participants in strings that range from 3 to 7 letters over 15 trials. An absolute score is derived from summing the total number of trials that the participant recalled all of the letters correctly. Scores range from 0-75. Both the internal consistency (α = .78) and test-retest reliability (α = .81) for the operation span task have been shown to be satisfactory (Unsworth et al., 2005). Additionally, the internal consistency (α =.78 - .83) and test-retest reliability (α =.76) of the reading span task have been shown to be adequate (Redick et al., 2012).

Inhibition Tasks

Spatial Compatibility. The Spatial Compatibility task (Simon & Rudell, 1967) requires participants to respond to a stimulus using the defined 'red' (left hand) or 'green' (right hand) key. On each trial a fixation cross appears at the centre of the screen for 500 milliseconds (ms). Following this a right or left pointing arrow appears on either the right or left side of the computer screen. Participants need to quickly and accurately respond to the direction the arrow is pointing regardless of the side of the screen on which it is presented. On compatible trials the arrow is pointing in the same direction as the side of the screen it is on (e.g., the arrow is on the right side of the screen and it is pointing to the right), whereas the arrow is pointing opposite the direction as the side of the screen it is on during incompatible trials (e.g., the arrow is on the left side of the screen and is pointing right). The participant needs to inhibit responses to the spatial position of the stimulus on incompatible trials. On each trial the participant must respond within 2000 ms, otherwise the trial is flagged as an omission. An average response time (RT) was calculated by assessing RT's of correct responses to incompatible trials, wherein a faster response time reflected better inhibition. The task consists of 48 trials, in which 24 compatible and 24 incompatible trials are inter-mixed in a random order.

Flanker task. During the Flanker task (Eriksen & Eriksen, 1974) participants are to respond correctly to the direction of a middle arrow using the aforementioned 'red' or 'green' keys. On each trial participants are shown a fixation cross at the centre of the screen for 500 ms. This is followed by a set of five arrows in a horizontal line at the centre of the screen. The middle arrow is surrounded by arrows (flankers) that are facing the same way on compatible trials, and by arrows that are facing the opposite way on incompatible trials. Participants are required to inhibit responding to the direction of the flankers on incompatible trials. Again, responses over 2000 ms are recorded as an omission. An average RT was again determined by assessing RT's of correct responses to incompatible trials. Again, faster response times are indicative of better inhibition. This task has 48 total trials, of which 24 are compatible trials and 24 are incompatible trials inter-mixed in a random order.

Stop Signal. The Stop Signal task (Logan, Cowan & Davis, 1984) requires participants to respond quickly and accurately to a red or green star that is presented on a monitor by either hitting the ‘red’ or ‘green’ key. On each trial a central fixation cross appears for 500 ms, after which the green or red star appears. Participants need to inhibit their response when the red or green star is followed by a tone. This requires the participant to inhibit an immediate response to the stimulus until they are certain that a tone will not play, and then to respond quickly before the stimulus disappears. The stimulus disappears after 2000 ms if no valid response is detected. This task has four blocks with 32 trials per block. Eight of the 32, or 25% of the trials have the tone (no-go trials), while 24 trials (75%) do not have a tone (go trials). Participants are allowed a short break between testing blocks to reduce fatigue. Timing of the tone was determined using a dynamic tracking algorithm where individuals were able to inhibit their response on approximately 50% of trials. Accordingly, the tracking algorithm adjusts for individual differences between and within participants. The mean delay of the stop signal was subtracted from the average time taken to respond to the stimulus. This resulted in an index of response inhibition (SSRT). As with the other two tasks, faster response times correspond to better inhibitory ability.

Self-report Questionnaires

*Positive and Negative Affect Schedule***.** The PANAS was used to assess how participants felt in general over the past few weeks. The PANAS is a 20-item scale, which requires participants to indicate how they have been experiencing both positive and negative mood adjectives (e.g. excited, afraid) on a 5-point Likert scale ranging from (1) very slightly or not at all to 5 (extremely). There are 10 items relating to positive affect and 10 items relating to negative affect. The PANAS has been validated to be used to measure affect over the past few weeks and in the present moment. The scale measuring affect over the past few weeks has good internal consistency for both the positive (α = .87) and negative factors at (α =.87) (Watson, Clark & Tellegen, 1988). We found similar reliabilities for the positive affect (α = .9) and negative affect (α = .85) subscales.

Emotion Reactivity Scale. The ERS is a 21-item scale that examines participants' experiences of emotions when reacting to emotional events using a 5-point Likert scale ranging from 0 (not at all like me) to 4 (completely like me). The ERS measures three indices of emotional reactivity: emotional sensitivity, emotional persistence and emotional arousal/intensity. The emotional sensitivity subscale contains eight items such as, "my feelings get hurt easily". The emotional persistence subscale is a three-item scale involving items such as, "when something happens that upsets me, it's all I can think about for a long time". The emotional arousal/intensity subscale has 10 items including, "when I experience emotions I feel them very strongly/intensely". Items are summed to give an ERS total score with a range from 0 – 84. The ERS demonstrates strong internal consistency with an overall alpha of .91 (Nock Wedig, Holmberg & Hooley, 2008). We observed similar internal consistency with an overall alpha at .93.

Emotion Regulation Questionnaire. The ERQ, developed by Gross and John (2003), assesses two widely used emotion regulation techniques, expressive suppression and cognitive reappraisal. There are six items assessing cognitive reappraisal and four items assessing expressive suppression measured on a 7-point Likert scale ranging from 1 (strongly disagree) to 7 (strongly agree). Items looking at cognitive reappraisal include questions such as, "when I want to feel more positive emotion, I change what I am thinking about", while items measuring expressive suppression include items such as, "I control my emotions by not expressing them". This 10-item scale has been shown to have satisfactory reliability for the expressive suppression (α = .73) and cognitive reappraisal factors (α = .79; Melka, Lancaster, Bryant & Rodriguez, 2011). For the ERQ subscales we observed an alphas of .65 for both cognitive reappraisal and expressive suppression.

Brief Symptom Inventory. The BSI is a 53-item scale that asks participants about a wide range of psychosomatic symptoms that many people experience. The BSI is the shortened version of the Symptom Checklist – 90 (SCL-90) and includes indices for somatization, interpersonal sensitivity, phobic anxiety, depression, hostility, anxiety, paranoid ideation, psychoticism, and obsessive-compulsive tendencies, as well as a general symptoms index which reflects overall psychological distress (GSI). Responses are measured on a 5-point Likert scale ranging from 0 (not at all) to 4 (extremely) based on how much participants agree with the experience of the statements over the past week. The GSI is an average of all the subscales and has high internal consistency at $\alpha = .9$ (Derogatis & Melisaratos, 1983). In our study we observed similar internal consistency for the GSI at $\alpha = .95$

Results

Analytic Approach

To reduce the number of EF measures used in analyses, composites were created by aggregating standardized scores on the working memory (Letter-number Sequencing, Operation Span and Reading Span) and inhibition (Flanker, Spatial Compatibility and Stop Signal tasks) measures. To retain similarity with the outcome measure from the Stop Signal task (i.e., the SSRT), we controlled for participant's processing speed in both the Flanker and Stop Signal tasks by entering compatible trial RTs on these tasks in regression models predicting incompatible trial RTs and saving residuals from these analyses. Residuals from both these tasks were then standardized and added to the standardized SSRT to form an inhibition composite. Correlations between tasks forming the inhibition and working memory composites are presented in Tables 1 and 2. All performance-based and questionnaire data were inspected for univariate, bivariate, and multivariate outliers and for normality. Four outliers were identified for having an incompatible average RT that was over three standard deviations above the group mean on the Flanker task. There was also one outlier identified for having an incompatible average RT that was over three standard deviations above the group mean on the Spatial Compatibility task and one outlier with an average SSRT that was over three standard deviations above the group mean on the Stop Signal task. All outliers had the outlying average RT's reduced to three standard deviations above the mean. No multivariate outliers were identified and all dependant measures were approximately normally distributed.

Related to the first aim, bivariate correlations were used to examine associations between EF abilities (i.e., WM and inhibition) and ER strategies (i.e., cognitive reappraisal and expressive suppression). To address the second aim, which was to examine the independent and joint association of EF and ER with psychological well-being, three separate multiple regressions models were created in which positive affect, negative affect and psychological distress were dependent variables and EF abilities (i.e., WM and inhibition), ER strategies (i.e., cognitive reappraisal and expressive suppression), and interactions involving EF and ER (e.g., WM x cognitive reappraisal) were mean centred and entered simultaneously as predictors. All variables were centered prior to creation of the interaction terms. To address the final aim of the study, which was to examine how the independent and joint association of EF and ER with psychological well-being may vary as a function of emotional reactivity, similar regression models were run with emotional reactivity as an additional predictor (e.g., emotional reactivity, emotional reactivity x inhibition, emotional reactivity x inhibition x cognitive reappraisal). In each analysis, significant effects (i.e., $p < .05$) are interpreted and trends (i.e., $p < .10$) are reported. Means and standard deviations for all measures are presented in Table 3. The multiple regression models described above were tested using PROCESS (Hayes, 2014) to investigate the locus of the interactions. The simple slopes for the association the predictors were tested at low (-1 SD below the mean), and high (+1 SD above the mean) levels (see Aiken & West, 1991).

Association of EF and ER

As shown in see Table 2, there was no significant association of inhibition with either cognitive reappraisal, $r = .12$, $p = .29$, or expressive suppression, $r = .02$, $p = .86$. Similarly, working memory was not significantly associated with either cognitive reappraisal, $r = .14$, $p = .19$, or expressive suppression, $r = -.07$; $p = .50$.

Independent and joint association of EF and ER for affect and psychological distress

With positive affect as the dependant variable, 21% of the variance was explained by predictors in the model (R^2 = .21, F(8, 77) = 2.62, p =.014). Significant predictors included cognitive reappraisal (β = .31, t(77) = 2.93, p =.005) and expressive suppression (β = -.24, t(77) = -2.31, p = .023), as well as the interaction between expressive suppression and inhibition (β = -.21, t(77) = -2, p = .049) (Figure 1). Subsequent analyses demonstrated there was a trend-level effect of inhibition on positive affect at low levels of expressive suppression, t(82) = 1.86, p = .066, but not at high levels of expressive suppression, t(82) = -.37, p = .71. This trend-level interaction suggests that those who use less expressive suppression experience more positive affect when they have low inhibitory skills than when they have high inhibitory ability. Conversely, there is no difference in amount of positive affect reported between high and low inhibitory ability for those reporting high use of expressive suppression. For negative affect as the dependent variable, the model was not significant (R^2 = .16, F(8, 77) = 1.85, p =.081). Finally, a regression with psychological distress as the outcome variable explained 31% of the variance (R^2 = .31, F(8, 77) = 4.23, p < .001). In this model, expressive suppression (β = .40, t(77) = 4.16, p < .001) and inhibition (β = -.24, t(77) = -2.44, p = .017) were significant predictors and there was also a trend towards a significant interaction of inhibition and cognitive reappraisal (β = .19, t(77) = 1.92, p = .058). Results are presented in Table 3.

Independent and joint association of EF and ER with psychological well-being as a function of emotional reactivity

For positive affect as the dependant variable, the model including emotional reactivity and all other predictors was no longer significant (R^2 = .31, F(17, 68) = 1.8, p = .052). For negative affect as the dependent variable, a model with all predictors explained 53% of the variance (R^2 =

.53, $F(17, 68) = 4.56$, $p < .001$). Emotional reactivity was a significant predictor ($\beta = .62$, $t(68) = 6.02$, $p < .001$), as was the interaction of emotional reactivity and inhibition ($\beta = -.33$, $t(68) = -2.98$, $p = .004$) (Figure 2). Simple slopes analysis revealed a significant effect of inhibition on negative affect for both high ($t(82) = 2.44$, $p = .017$) and low ($t(82) = -2.04$, $p = .045$) levels of emotional reactivity – albeit in the opposite direction. The interaction suggests that those high in emotional reactivity had more negative affect when they also had higher inhibitory ability, while those low in emotional reactivity had less negative affect when they also had higher inhibitory ability. Finally, a regression with psychological distress as the outcome variable explained 68% of the variance ($R^2 = .68$, $F(17, 68) = 8.32$, $p < .001$). In this model, emotional reactivity ($\beta = .64$, $t(68) = 7.37$, $p < .001$) and expressive suppression ($\beta = .26$, $t(68) = 3.41$, $p = .001$) were both significant predictors of psychological well-being. There were also trend-level interactions between cognitive reappraisal and inhibition ($\beta = .17$, $t(68) = 1.93$, $p = .058$) and between cognitive reappraisal, inhibition and emotional reactivity ($\beta = .18$, $t(68) = 1.74$, $p = .087$). Results are presented in Table 4.

Discussion

Research has demonstrated that EF and ER are supported by a common neurological substrate and have common associations with affective experiences and mental-health; however, no studies to our knowledge have simultaneously explored the unique and joint effects of EF and ER relative to emotional outcomes in a single multivariate model, nor have any examined how these associations may be moderated by individual differences in emotional reactivity. To address this gap in our knowledge, the current study was undertaken to investigate the interplay of EF, ER, and emotional reactivity vis-à-vis positive and negative affect and psychological distress. Specific questions included (1) what association is present between EF abilities and ER strategy use, (2) how are EF and ER related to positive and negative affect and psychological distress, and (3), what impact does emotional reactivity have on the relationship between EF and ER on emotional outcomes. To address these questions, participants completed self-report questionnaires measuring emotion regulation, emotional reactivity, emotional experience and psychological distress. They also completed a battery of EF tasks measuring inhibition and working memory.

Regarding the first question that was addressed in our study, we hypothesized that EF abilities and ER strategies would be related. In the current study, however, we found no evidence to support the idea that inhibition and working memory are associated with cognitive reappraisal or expressive suppression. Although EF and ER are both self-regulatory skills, the lack of association suggests that individual differences in working memory and inhibitory abilities are not predictive of the extent that an individual uses either cognitive reappraisal or expressive suppression in an effort to regulate his/her emotional experiences. Contrary to our null findings, this association has been demonstrated in previous research. For example, a study with healthy preschool-aged children found that children who had better inhibitory ability also demonstrated increased expressive suppression (Carlson & Wang, 2007). Whilst this study points to a correlation of EF and ER, longitudinal research has found that these constructs may be causally related (Ursache et al., 2013). Specifically, it was found that more adaptive ER at 15 months of age predicted better-developed executive abilities at age four. Interestingly, this effect was moderated by emotional reactivity, such that only those were high in emotional reactivity who demonstrated a positive impact of ER at 15 months on EF later in development. Both EF and ER undergo significant development during early childhood through to adolescence. Thus, these findings may suggest that EF and ER have a stronger relation during childhood due to similar developmental trajectories (Huizinga et al., 2006; Lehto et al., 2003; Silvers et al., 2012), but diverge later in development, perhaps explaining why we found no evidence of association between EF and ER in young adulthood.

It also is worth noting that a few studies have examined associations between EF and EF in adulthood. Two studies with neurologically compromised adults that suggest that EF and ER may be related beyond the childhood years. One study of a sample of individuals with a diagnosis of Multiple Sclerosis found that ER ability was positively related to verbal fluency (Philips et al., 2014), which was replicated in another study of individuals with a diversity of neurodegenerative disorders (Gyurak et al., 2012). Though verbal fluency is not traditionally viewed as an EF ability, it has been suggested that this ability requires organization and planning which are central to goal oriented behaviour (Gyurak et al., 2012). Also in opposition to our findings, a study by Bridgett and colleagues (2013) has proposed a link between working memory and cognitive reappraisal, and inhibition and expressive suppression in a healthy adult sample. Although the authors did not formally test this hypothesis, they found that increased inhibitory ability was related to lower expression of negative emotions, while high working memory ability was associated with decreased experience of negative affect. In their discussion the authors suggested that the expression of negative emotions could relate to expressive suppression and that the experience of negative emotions might be associated with cognitive reappraisal. In the current study, we found no evidence that cognitive reappraisal or expressive suppression were related to working memory or inhibition, nor were we able to replicate the finding that working memory was associated with the experience of negative affect. Given that no research with healthy adults has demonstrated this pattern of results, to our knowledge, it may be that these findings are particular to individuals with neurological disorders and would not generalize to adults in whom the brain has not been compromised.

Given that in the current study working memory and inhibition were measured through performance measures while expressive suppression and cognitive reappraisal were measured via self-report, it may be that the potential relationship between EF and ER was attenuated due to methodological differences in the measures that were used to assess each of these constructs. It also is worth mentioning that these measures may assess these constructs on differing time frames. For example, the ERQ asks individuals how they generally respond to their emotional experiences whereas performance measures of EF assess executive skills at a specific time point. It also has been suggested that performance-based measures of EF may not capture an individual's ability to apply his/her executive skills in the more naturalistic environment of real life (Barkley, 1997; Toplak, West & Stanovich, 2013). Although any or all of these explanations may account for the null finding reported in our study, we note that, recent research collected in our lab using only self-report measures to assess general EF and ER in young adults has also failed to find a reliable relationship between EF and ER – even with shared method variance and sampling over a similar time frame. Though speculative, it may be the case that individuals are not able to accurately report on self-regulatory processes such as EF and ER. Future research could explore this idea by incorporating multi-informant ratings of these constructs (i.e., EF and ER ratings provided by self and others) and by also including direct measures of both EF and ER in addition to the rating scales in a single study.

Regarding the second question that was addressed in our study, we hypothesized that positive affect would be predicted by cognitive reappraisal and expressive suppression, that negative affect would be predicted by cognitive reappraisal, expressive suppression and working memory and that psychological distress would be predicted by cognitive reappraisal, expressive suppression, working memory and inhibition. Our findings suggest that whilst EF and ER are not inter-related constructs, they are both predictive of affective experiences and psychological distress. For positive affect, individuals who endorsed more use of cognitive reappraisal also reported greater positive affect, while individuals who disclosed more use of expressive suppression reported lower positive affect. This finding is consistent with that of Gross and John (2003), who have reported that increased use of expressive suppression is associated with less positive affect and that increased use of cognitive reappraisal is related to more positive affect. Interestingly, we also found that positive affect was predicted by individuals' inhibitory ability – however, the nature of this association was moderated by their endorsement of expressive suppression. Specifically, whilst there was no evidence of association between inhibition and positive affect for individuals who endorsed relatively high amounts of expressive suppression, there was a trend toward an association for individuals in whom use of expressive suppression was relatively low – such that lower levels of inhibition were associated with more positive affect. This interaction requires replication in future work, but raises the possibility that individuals who use less expressive suppression may experience negative outcomes if they also have good inhibitory ability. As mentioned, Carlson and Wang (2007) have found that good inhibitory ability was related to increased expressive suppression. Thus, expressive suppression may be beneficial to emotional outcomes when inhibition is strong. However, this would suggest that those high in suppression with good inhibitory ability should show the opposite trend which we did not find in our study. Future research should aim to replicate our findings with a larger sample size to support or refute this hypothesis.

Regarding the third aim of the study, we hypothesized that emotional reactivity would moderate effects of ER use such that those high in emotional reactivity who also utilized less expressive suppression or more cognitive reappraisal would have more adaptive outcomes (i.e., more positive affect, less negative affect and less psychological distress). In fact, inclusion of emotional reactivity added a considerable amount of explanatory power to models in which negative affect and psychological distress were outcomes. For negative affect, previous research has demonstrated that increased use of expressive suppression and decreased use of cognitive reappraisal is associated with increased negative affect (Gross & John, 2003). Interestingly, when emotional reactivity was entered as a predictor into our model, fewer of these results were found. Specifically, our results suggest that emotion regulation strategies do not uniquely predict negative affect once emotional reactivity and inhibitory ability are taken into account. Inspection of our significant emotional reactivity x inhibition interaction revealed an interesting pattern of findings – namely, that inhibitory ability was positively associated with negative affect for individuals low in reactivity (i.e., better inhibition predicted less negative emotion), but was negatively associated with negative affect for individuals high in reactivity (i.e., better inhibition predicted more negative emotion). Regarding this interaction, the finding that low reactive individuals who have higher inhibition experience less negative affect than low reactive individuals with lower inhibition is supported by prior research. Tang and Schmeichel (2014) used a lab-induced emotional manipulation prior to completing inhibitory tasks and found that better inhibitory ability was predicted by the absence of negative feelings. They acknowledged that reactivity may further impact the degree to which negative feelings are endorsed or regulated and that this may in turn affect inhibitory ability. Though the authors did not directly test what effect reactivity had on this relationship, it may help to explain the pattern of results that we found in the current study.

While we found results similar to what was observed in the research study by Tang and Schmeichel (2014) for low reactive individuals, we found that highly reactive individuals with high inhibition experience more negative affect than those with low inhibitory ability. Given the strong predictive effect of emotional reactivity on negative affect it might be that this interaction is performance dependent based upon the individuals typical affective state. This would mean that those high in emotional reactivity are typically higher in negative affect and that they perform better on inhibitory tasks under these conditions. An example that might parallel this situation would be those who perform better under pressure versus those who do not perform well under pressure. There are a couple of limitations to this explanation however. Firstly, if it were true that performance on inhibitory tasks was dependent upon typical affective state then one might expect a similar trend regarding the interaction between working memory ability and emotional reactivity on negative affect – which was not observed in our study. Secondly, since there is also a predictive effect of emotional reactivity on psychological distress it stands to reason that there should also be a significant interaction between emotional reactivity and EF abilities and psychological distress. Exploration of this idea with post-hoc analyses, with inhibitory ability as the predictor and reactivity as the moderator, produced the same pattern for psychological distress as an outcome measure (i.e., those who are highly reactive and have lower inhibitory ability have lower psychological distress than highly reactive individuals with high inhibitory ability); however, the opposite trend for low reactive individuals is not present (see Figure 3). It would be interesting to know how reactivity might affect scores on measures of EF that assessed how individuals function in general as opposed to measuring EF at one particular time. It would be reasonable to hypothesize that differences between the low and high reactivity groups might disappear. This could be due to the measure not being performance based and thus EF ability would not be affect state dependant. Another option would be to have individuals tested at multiple times and have measures of affect and psychological distress administered directly before each time-point assessing how they are feeling at that time. This could then be compared to performance on EF tasks at different time-points and measures of emotional reactivity, affect and psychological distress based on how participants feel in general. Yet another option might include comparing two groups of individuals on EF tasks. The first group would complete EF tasks involving an emotional component similar to research carried out by Tang and Schmeichel (2014). This would provide measures of emotional reactivity and ER strategies that could be measured through self-report or behavioural observation. The second group would complete unemotional measures of EF, such as the ones involved in the current study. These two groups could then be compared based on between group differences on EF measures as well as within groups via differences in emotional reactivity.

For psychological distress, a model without emotional reactivity revealed that individuals who endorsed more use of expressive suppression and who had better inhibitory ability endorsed more mental-health concerns. The finding that expressive suppression shares a positive relation with psychological distress replicates findings by Gross and John (2003) suggesting that expressive suppression is related to more negative psychological outcomes. However, it is interesting that higher inhibitory ability was associated with more psychological distress as well. Based on previous research examining the association between executive dysfunction and mental health difficulties (Barkley, 1997; Lipszyc & Schachar, 2010; Gillberg et al., 2010; Ikeda et al., 2013; Wingo et al., 2013; Visu-petra et al., 2013), it was expected that better inhibitory ability would be related to less psychological distress. Nonetheless, this particular result is at least consistent with our finding that those who use less expressive suppression report less positive affect when they have low inhibitory ability. When emotional reactivity was added to the model, reactivity and expressive suppression were both significant predictors but the previously observed effect of inhibition was no longer apparent. It is clear that emotional reactivity has a strong effect on psychological distress and negative affect even when controlling for ER strategy use. Moreover, when reactivity was entered into the model inhibition dropped out as a significant predictor of psychological distress. Thus, future research involving EF and ER should control for related emotional reactivity awareness when considering effects of EF and ER on emotional experience and psychological distress.

The current study adds to our understanding of the ways in which EF, ER, and emotional reactivity contribute to emotional experiences and mental-health; however, our findings should be interpreted in the context of several limitations. First, our sample consisted of primarily female undergraduate students who may not be representative of the general population. Replicating this work with additional groups (e.g., adult community samples, older populations or adolescent samples), may attest to the generalizability of our findings or identify possible boundary conditions of our results. Second, we only measured inhibition and working memory at one time-point. Although we used three tasks to get a reliable composite of EF abilities, it would have been ideal to get multiple measures of these abilities, as any of the participants could have been having an exceptionally good or bad day based on amount of sleep, stress, or physical health reasons. Research has shown that performance on EF tasks are reduced during sleep deprivation (Tucker, Whitney, Belenky, Hinson & Van Dongen, 2010), and under stress (Schoofs, Wolf & Smeets, 2009). Third and related to the last point, sleep, stress, and physical health could have biased participants' responses to emotional measures such as the PANAS, ERQ, ERS or BSI. Measuring these constructs at multiple times would have also been useful. Finally, self-report measures of self-regulatory abilities such as EF and ER require a certain amount of insight, which those deficient in these abilities may not have. Accordingly, obtaining physiological or behavioural information indicating use of ER strategies would have been beneficial in measuring this construct. Future research should aim to rely less heavily on self-report measures to get a more objective index of self-regulatory abilities.

In conclusion the current study explored the relationship between EF, ER, emotional reactivity and emotional and psychological outcomes. Although we were unable to extend findings indicating a relationship between EF and ER, indicators from both of these constructs were predictive of positive affect, negative affect and psychological distress. Furthermore, emotional reactivity significantly impacted the relationships of expressive suppression on negative affect and expressive suppression and inhibition on psychological distress. This suggests that emotional reactivity has a role in explaining these relationships and future research examining aspects of EF and ER should include this construct.

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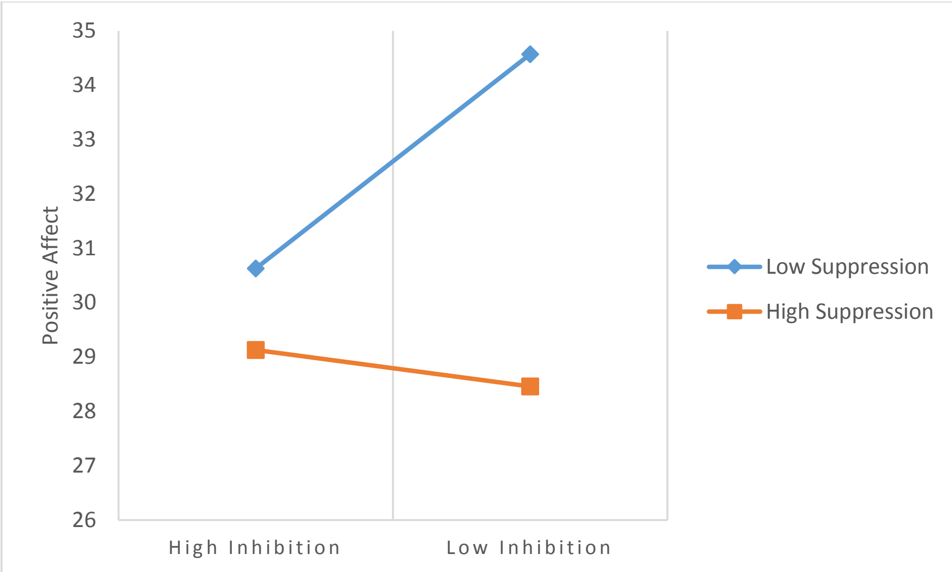

Figure 1. Interaction between inhibition and expressive suppression on positive affect.

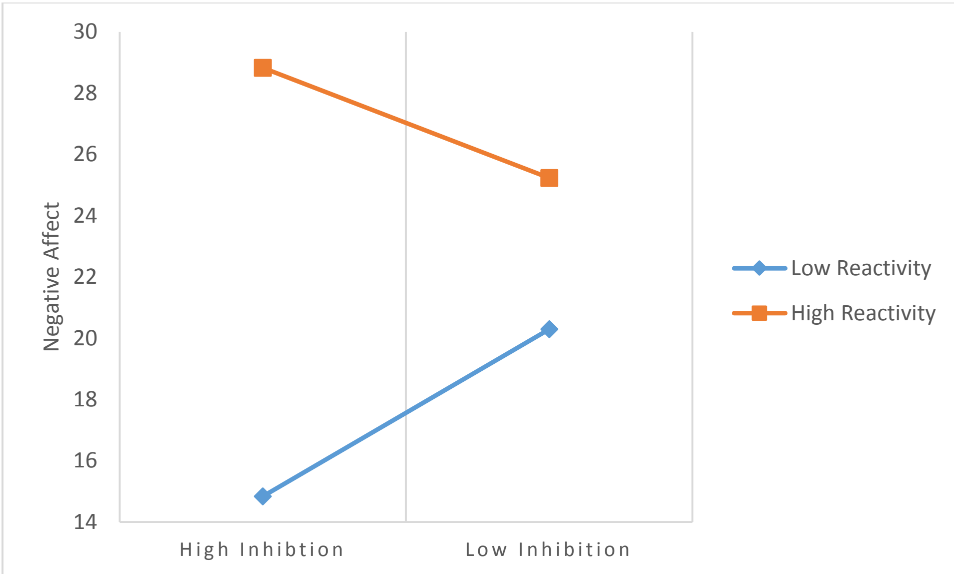

Figure 2. Interaction between inhibition and emotional reactivity on negative affect.

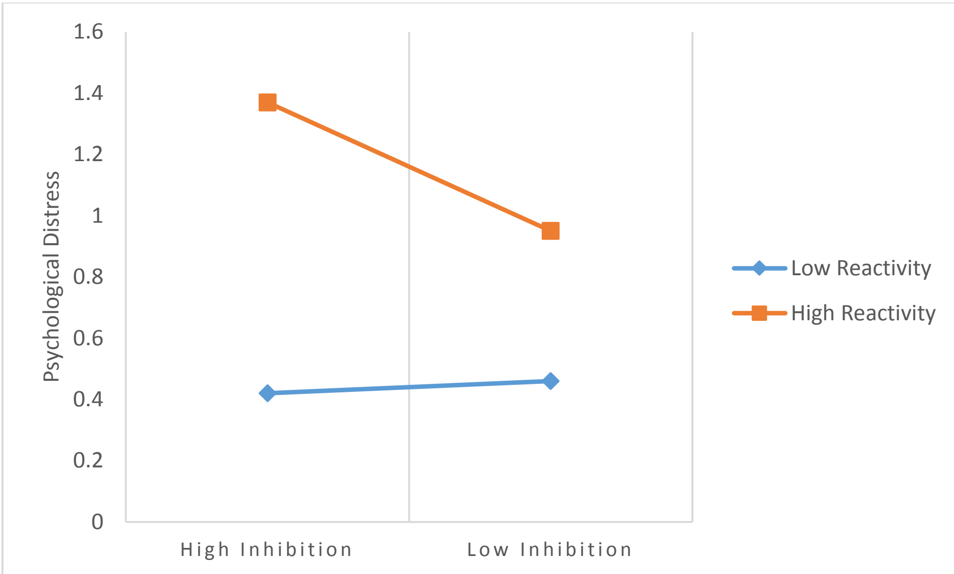

Figure 3. Interaction between emotional reactivity and inhibition on psychological distress.

Table 1.

Correlations between tasks comprising the inhibition composite.

Construct	1	2	3
1. Flanker**	-		
2. Stop Signal	**.37***	-	
3. Spatial Compatibility**	**.30***	**.35***	-

* $p < .05$

** Processing speed is controlled for within these tasks

Table 2.

Correlations between tasks comprising the working memory composite.

Construct	1	2	3
1. Reading Span	-		
2. Operation Span	**.55****	-	
3. Letter-number Sequencing	**.43****	**.36***	-

* p < .05
** p < .001

Table 3.

Means and standard deviations of all predictors and outcome variables.

Measure	Mean	Standard Deviation
ERQ: Cognitive Reappraisal (sum)	30.94	5.25
ERQ: Expressive Suppression (sum)	15.01	4.46
ERS Total (sum)	29.52	15.16
Inhibition Composite	-.22	1.97
Flanker Incompatible RT (ms)	452.88	60.93
Spatial Compatibility Incompatible RT (ms)	520.98	84.96
Stop Signal RT (ms)	303.35	50.28
Working Memory Composite	.20	2.33
Operation Span (absolute score)	44.94	17.9
Reading Span (absolute score)	35.77	17.13
Letter-number Sequencing (total correct)	21	2.21
Total PANAS Positivity	30.67	6.85
Total PANAS Negativity	22.48	8.47
Average General Severity Index	.81	.61

Table 4.

Correlations between cognitive reappraisal, expressive suppression, working memory and inhibition.

Construct	1	2	3	4
1. Cognitive Reappraisal	-			
2. Expressive Suppression	-.11	-		
3. Working Memory	.14	-.07	-	
4. Inhibition	.12	.02	-.12	-

Table 5.

Regression with ER strategies and EF abilities as predictors of positive affect, negative affect and psychological distress.

	Positive Affect		Negative Affect		General Severity Index	
	B	S.E.	B	S.E.	B	S.E.
Expressive Suppression	**-.37***	**.16**	**.57***	**.20**	**.06****	**.01**
Cognitive Reappraisal	**.42***	**.15**	.12	.17	.009	.01
Inhibition	.36	.36	-.21	.47	**-.07***	**.03**
Working Memory	-.04	.31	-.27	.39	.03	.03
Suppression x Inhibition	**-.15***	**.08**	**-.20***	**.10**	-.006	.006
Suppression x Working Memory	.004	.08	-.04	.10	.004	.006
Reappraisal x Inhibition	-.09	.06	.004	.08	**.01†**	.005
Reappraisal x Working Memory	-.01	.07	-.01	.09	.007	.006
R^2	**.21***		.16		**.31****	

† p < .10
* p < .05
** p < .001

Table 6.

Regression with ER strategies, EF abilities and emotional reactivity as predictors of positive affect, negative affect and psychological distress.

	Positive Affect		Negative Affect		General Severity Index	
	B	S.E.	B	S.E.	B	S.E.
Emotional Reactivity	.07	.06	**.35****	**.06**	**.03****	**.003**
Expressive Suppression	**-.46***	**.17**	.26	.17	**.04****	**.01**
Cognitive Reappraisal	**.42***	**.15**	.18	.15	.02	.009
Inhibition	.27	.46	.51	.46	-.03	.03
Working Memory	-.008	.32	-.55	.32	.02	.02
Reactivity x Suppression	.02	.01	-.005	.01	.000	.001
Reactivity x Reappraisal	.01	.01	-.005	.01	.000	.002
Reactivity x Inhibition	.02	.03	**-.09***	**.03**	-.002	.002
Reactivity x Working Memory	.004	.02	-.02	.02	.000	.001
Suppression x Inhibition	**-.25***	**.10**	-.05	.10	.004	.006
Suppression x Working Memory	.06	.09	-.12	.09	.001	.005
Reappraisal x Inhibition	-.07	.07	-.10	.07	.009	.004
Reappraisal x Working Memory	.04	.08	-.07	.08	.006	.005
Reactivity x Inhibition x Suppression	.01	.007	-.007	.007	.000	.000
Reactivity x Inhibition x Reappraisal	.003	.006	.009	.006	.001	.000
Reactivity x Working Memory x Reappraisal	-.01	.005	-.001	.005	.000	.000

Reactivity x Working Memory x Suppression	-.006	.007	-.003	.007	.000	.000
R^2	.31†		**.53****		**.68****	

† $p < .10$
* $p < .05$
** $p < .001$.