TEMPORAL EFFECTS OF TOP-DOWN EMOTION REGULATION STRATEGIES ON AFFECT, WORKING MEMORY LOAD, AND ATTENTIONAL DEPLOYMENT

by

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THESIS

Presented to the Faculty of

The University of Houston-Clear Lake

In Partial Fulfillment

Of the Requirements

For the Degree

MASTER OF SCIENCE

in Psychology

THE UNIVERSITY OF HOUSTON-CLEAR LAKE

AUGUST, 2022

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Dedication

To my son: thank you for being so patient and kind and sharing your time with your mom as she followed her passion. You teach me with your golden heart each day, Leonin.

Acknowledgements

I thank my family and friends for lending me your ears when I overshared about my cognitive neuroscience passions over the years.

I would also like to thank my wonderful advisor, Dr. Georgina Moreno. My first course at UHCL was with you, as was my last. Over this full circle journey, you have given me the ideal combination of freedom and support to flow and flourish and find my own way in the vast sea that is neuropsychological research. Learning under your ever-present, yet trusting, leadership has been inspiring.

My acknowledgments would not be complete without including two graduate students who have genuinely helped propel this research project. Jerilyn, you are both incredibly kind and sharp. I am very thankful to have had you as a graduate research assistant on this project. Your contributions have been innumerable. In addition, Marie, thank you for jumping in headfirst with ideas to help get this project up and running in its early days.

Finally, Dr. Nicholas Kelling, thank you for your detailed guidance on key issues within the thesis. I believe your thoughtful insights have made this a better project. In addition, you have given me much to consider as I move forward in my long-term research objectives.

ABSTRACT

TEMPORAL EFFECTS OF TOP-DOWN EMOTION REGULATION

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Evrim Baykal
University of Houston-Clear Lake, 2022

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Prior research has elucidated the effectiveness of top-down emotion regulation strategies of cognitive reappraisal (CR) and guided attention (GA) at minimizing negative feelings while also being cognitively demanding. However, the mechanisms underlying these processes are not well understood. The current study uses eye-tracking to explore the temporal effects of two top-down emotion regulation strategies–cognitive regulation and guided attention–on attentional deployment, working memory load, and emotion regulation effectiveness. 54 participants (M_{age}=25.42±5.01yrs) completed an emotion regulation task while measuring pupillometry and gaze fixations. During the task, participants implemented CR or GA strategies while viewing negative images then rated their feelings. Two-way, repeated-measures ANOVA inferential statistical procedure was used to separately examine effects of strategy (guided attention vs cognitive reappraisal), time (brief, 4s vs sustained, 8s), and strategy by time interactions on emotion regulation effectiveness (self-reported affect), working memory load (inter-trial change in pupil diameter), and attentional deployment (% of total trial fixations on AOI). Analyses revealed sustained duration trials (8s) yielded greater fixations to negative stimuli as compared to brief duration trials (4s), while emotion regulation effectiveness was not significantly changed. CR resulted in higher fixations to negative AOI than GA yet was more effective at regulating emotion. In conclusion, this work suggests that implementing top-down emotion regulation may sustain emotion regulation effectiveness, and CR particularly maintains emotion regulation effectiveness. A better understanding of the temporal effects of top-down emotion regulation strategies on affect, attentional deployment, and working memory could reveal more insight into differences in interpreting and behaviorally responding to emotional stimuli.

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CHAPTER I:

INTRODUCTION

Emotions move through a sequence of four stages: stimulus, attention, appraisal, and response (Gross, 2002). Antecedent-based emotion regulation strategies, such as cognitive reappraisal and guided attention, exert a top-down influence on regulating emotions and occur primarily before behavioral, experiential, and physiological responses (Strauss et al., 2016). In contrast, response-based strategies, such as repression or distraction, have a bottom-up influence on emotion regulation and primarily occur after a behavioral, experiential, and physiological response to stimuli has begun (Gross, 1998). Top-down emotion regulation strategies are triggered before full activation of an expression of a given emotion (Gross & Thompson, 2007), while bottom-up strategies are actions implemented after an emotion trajectory begins (Blumberg et al., 2016).

Attention and Top-down Emotion Regulation

The effect of emotion on attention has been well documented (e.g., Tyng et al., 2017, Barbot & Carrasco, 2018), however a growing base of research proposes attention may also impact emotion (Oliveira et al., 2013; Yamaguchi & Onoda, 2012; Dolcos, Katsumi, et al., 2020). In fact, emotion may dynamically interact with attention to influence behavior and affect over time (Ferri & Hajcak, 2015).

Attention can have both a maladaptive and productive effect on emotion regulation (Waldinger & Isaacowitz, 2011). For example, individual differences in attentional deployment, such as a propensity to direct eye focus to negative stimuli, have been linked to depression (Greimel et al., 2020) and anxiety (Barry et al., 2015). In addition, a tendency to passively attend to negative stimuli may indicate susceptibility to threat bias (Wieser & Keil, 2020), a dysfunctionality of threatening stimuli attendance. Conversely, top-down guided attention - engaging attention away from negative stimuli early on in attention - has been shown helpful at increasing self-reported positive affect as compared to bottom-up suppression (Dolcos, Bogdan, et al., 2020). While bottom-up suppression is the inhibition of affective or behavioral response to negative stimuli, top-down guided attention reduces the need to regulate emotion upstream, compared to bottom-up suppression (Dolcos, Bogdan, et al., 2020; Gross, 1998).

Neural Correlates of Top-down Emotion Regulation

Top-down and bottom-up emotion regulation present differently not only in affective and behavioral response, but also neurally. Amygdala activity has been implicated in both up- and down-modulation in accordance with emotion regulation goals (Ochsner et al., 2004; Moodie et. al., 2020). However, neural substrate studies of top-down, antecedent-based strategies, such as cognitive reappraisal and guided attention, demonstrate that if negative emotion producing stimuli are not reframed early on in attention, deeper limbic substrates become more engaged (Mauss et al., 2007). If the deeper limbic system becomes engaged, emotion regulation becomes bottom-up, and the stimuli can either be suppressed or passively attended to without suppression. Continued passive attendance, or suppression, to a negative stimulus can create greater neural arousal in the limbic system (Wieser & Keil, 2020). Top-down attentional deployment effort may help modulate amygdala activity (Ferri et al., 2013), while habitual bottom-up suppression may enhance connections between the more medial prefrontal cortical regions and the amygdala **(**Hermann at al., 2014).

In addition, top-down reappraisal and bottom-up suppression may have non-congruent neural pathways and divergent cognitive burdens (McRae et al., 2012). Cognitive reappraisal has frequently been shown to reduce amygdala activation, likely due to larger gray matter volumes in amygdala subregions influenced by cognitive reappraisal's inhibitory processes (Ochsner & Gross, 2005). More habitual use of cognitive reappraisal to regulate emotions enhances bilateral amygdala gray matter volume, possibly as a consequence or even prerequisite of enhanced use of cognitive reappraisal as an emotion regulation strategy (Hermann et al., 2014). In fact, multiple studies indicate reduced amygdala gray matter volumes in several different psychiatric disorders involving emotional processing deficits and dysregulation (Shepherd et al., 2012). Increased amygdala volume may reflect increased emotional control, due to more effective implementation of reappraisal (Hermann et al., 2014). Top-down emotion regulation strategies such as cognitive reappraisal may play a modulatory role between the prefrontal cortical regions and the amygdala.

Working Memory Load and Top-down Emotion Regulation

Working memory can be defined as a limited capacity, cognitive construct that provides processing power for several tasks involved in processes such as perception, executive functioning, verbal reasoning, and encoding/retrieval to/from long-term memory (Cowan, 1999; Baddeley, 2003; Baddeley & Hitch, 1974). Working memory engages in processes requiring information to be retained and manipulated (Chai et al., 2018) and in processes of emotion regulation (Rutherford et al., 2016; Jasielska et al., 2015). Since working memory is a shared space implicated in carrying out a variety of tasks, working memory load can be defined as burden placed on finite working memory capacity (Scharinger et al., 2017).

The effects of emotion regulation on working memory load have also been examined. Studies show working memory load increases with both bottom-up emotion regulation (Richards & Gross, 2000; Baumeister et al., 1998) and top-down emotion regulation (Sheppes & Meiran, 2008). Bottom-up and top-down emotion regulation of negative emotion have been shown to recruit cortical areas associated with cognitive control - anterior cingulate and prefrontal cortex (PFC) regions. More specifically, PFC regions linked to retrieving emotional knowledge (left rostromedial PFC) are associated with up-regulation and PFC areas linked to behavior inhibition (right lateral and orbital PFC) are associated with down-regulation (Ochsner et al., 2004).

Top-down emotion regulation strategies are associated with higher working memory load than bottom-up emotion regulation strategies (Strauss et al., 2016; Adamczyk et al., 2022). For example, recent work by Adamczyk and colleagues (2022) revealed that increased working memory load, as measured by a dual-task paradigm, facilitates bottom-up emotion regulation, while simultaneously impairing use of top-down cognitive reappraisal. In fact, higher working memory load may lower performance of cognitive reappraisal as an emotion regulation strategy (Gan et al., 2017, Thiruchselvam et al., 2011).

Top-down emotion regulation strategies - cognitive reappraisal (Richards & Gross, 2000; Sheppes & Meiran, 2008) and top-down attentional control (Strauss et al., 2016) - have both been linked to increased working memory load. An fMRI study by Fietz and colleagues (2022) demonstrated that working memory processing in an N-back task increased blood flow to cortical areas associated with top-down emotion regulation strategies of cognitive reappraisal and guided attention (Moodie et al., 2020).

Strauss and colleagues (2016) postulate that distraction in the form of top-down guided attention may utilize slightly less working memory processing than cognitive reappraisal. During a task requiring viewing of negative emotionally salient stimuli, working memory load, as measured by pupil dilation, was greater with reappraisal compared to guided attention (top-down attentional control). These findings suggest cognitive reappraisal may involve more effortful cognitive control processes than guided attention (Strauss et al., 2016), however this study has not yet been replicated.

Rising attention is being given to the distinct effects of top-down emotion regulation strategies on spatio-temporal dynamics in the brain, and results indicate a cortical shared space between top-down emotion regulation and working memory processing. Moodie and associates (2020) demonstrated that top-down emotion regulation strategies of guided attention and cognitive reappraisal preferentially activate frontoparietal control regions through "distancing" from negative stimuli.

In addition, cognitive reappraisal has been shown to activate dorsolateral (dlPFC) and ventrolateral (vlPFC) prefrontal cortex regions (Moodie et al., 2020). The vlPFC has been implicated in active cognitive reappraisal during a negative image viewing task (He et al., 2018, Fietz et al., 2022). Working memory processing utilizes these same brain regions (vlPFC and dlPFC) during cognitive reappraisal.

Temporal Effects of Emotion Regulation on Working Memory and Affective Response

Prior research has elucidated the effectiveness of top-down emotion regulation at modulating affective response as compared to bottom-up emotion regulation. Top-down cognitive reappraisal is effective at minimizing negative feelings with exposure to negative emotionally-salient stimuli (Sheppes & Meiran, 2007). Guided attention also helps regulate emotion after exposure to negative emotionally-salient stimuli (Dolcos, Bogdan et al., 2020).

Temporal factors may play a role in the effects of emotion regulation strategies on working memory demands and emotion regulation effectiveness. Cognitive reappraisal has been observed to significantly reduce working memory costs when implemented at the onset of the emotional situation (Gross, 2002). However, cognitive reappraisal may elicit a higher working memory demand, as measured by a Stroop task, than bottom-up distraction with delayed (3 minutes after viewing a negative emotionally salient video) implementation of the emotion regulation strategy (Sheppes & Meiran, 2008). Response-based, bottom-up distraction has also been shown to help regulate emotion (Gross, 1998), yet distraction's up-regulation efforts may lose effectiveness with longer stimuli exposure times (Sheppes & Meiran, 2007; Sheppes & Gross, 2011).

The temporal effects of emotion regulation on affective response and working memory load outcomes may be influenced by the spatio-temporal impacts of early attention in emotion regulation. Top-down emotion regulation occurs temporally earlier than bottom-up emotion regulation strategies and has different neuronal pathways (Dolcos, Bogdan, et al., 2020; Goldin et al., 2008). Additionally, a study by Goldin and colleagues (2008) demonstrated that when viewing 15 seconds of video depicting negative emotionally salient stimuli, participants showed increased prefrontal cortex activation from 0 to 4.5 seconds after exposure, along with decreased amygdala and insular response, as well as a decreased experience of negative emotion. In contrast, suppression resulted in PFC activation at longer exposure times, 10.5 to 15 seconds, along with overall increased insula and amygdala activity. The analysis showed that reappraisal results in significant reductions in effective down regulation of emotion, as demonstrated by emotionally linked neural signaling (i.e., amygdala and insular activity). However, these effects were more fully recognized when considering longer exposure times (i.e., a near steady decline in limbic activity from 0 seconds to 15 seconds of exposure).

Late positive potential (LPP) is an EEG/ERP component noted as a reliable marker for activation during attendance to emotionally-arousing versus neutral stimuli (Thiruchselvam et al., 2011; Yen et al., 2010; Brown et al., 2012; Dunning & Hajcak, 2009). and during cognitive reappraisal implementation (Kennedy & Montreuil, 2021). LPP's onset begins a few hundred milliseconds after stimulus viewing and lasts for approximately six seconds (Yen et al., 2010). Bottom-up emotion regulation (i.e., distraction) reduces LPP earlier in the emotion regulation process than cognitive reappraisal (Thiruchselvam et al., 2011). A recent study by Adamczyk and colleagues (2022) showed LPP amplitude was higher in top-down emotion regulation when working memory load was low vs when working memory load was high at onset of emotion regulation. These results suggest that high working memory load may be disruptive to reappraisal implementation, which further speaks to the importance of better understanding the temporal effects of emotion regulation strategies on working memory and affective response

The Current Study

In the current study, we examine the temporal effects (4s; 8s) of top-down emotion regulation strategies (GA; CR) on emotion regulation effectiveness (self-reported affect), working memory load (inter-trial change in pupil diameter), and attentional deployment (% of total trial fixations to AOI). Total trial fixations will be defined as the number of total eye gaze fixations to the computer screen during image viewing. Temporal effects will be defined by brief (4s) and sustained (8s) exposure times to negative emotionally salient stimuli. The specific 4 and 8 second exposure times are expansions of a study by Goldin (2008) that also examines divergent temporal effects of emotion regulation. Research by Goldin and colleagues (2008) demonstrated that 15 seconds of viewing negative emotionally salient stimuli increased prefrontal cortex activation up to 4.5 seconds after exposure and increased affective response. Examining exposure times at 4 and 8 seconds could yield a better understanding of the temporal dynamics of cognitive reappraisal and guided attention, allowing a less static picture of the effects of key top-down emotion regulation strategies on attentional deployment, working memory load, and affect.

Aims & Hypotheses

Aim 1: Comparing Guided Attention & Cognitive Reappraisal.

Aim 1 of this study is to explore a side-by-side comparison of two, key top-down emotion regulation strategies (i.e., guided attention and cognitive reappraisal) on emotion regulation effectiveness (self-reported affect), working memory load (inter-trial change in pupil diameter), attentional deployment (% of total trial screen fixations to AOI), and their interactions. Emotion regulation effectiveness will be measured by a 10-point affect rating scale anchored from very negative (1) to very positive (10). Attentional deployment will be measured by area-of-interest (AOI) gaze fixations (% of AOI fixations over total fixations during negative image viewing trials). Working memory load will be measured by inter-trial pupillary response.

It is hypothesized that, in line with earlier studies that demonstrate top-down emotion regulation strategy effectiveness, self-reported affect will not substantially decrease during implementation of top-down emotion regulation strategies (i.e., guided attention and cognitive reappraisal) during negative stimuli viewing (Dolcos, Bogdan, et al., 2020; Sheppes & Meiran, 2007; Robinson et al., 2021). Finally, it is hypothesized that cognitive reappraisal may be slightly more cognitively effortful than guided attention (Strauss et al., 2016).

Many prior studies have compared bottom-up emotion regulation strategies, such as expressive suppression, with top-down emotion regulation strategies, namely cognitive reappraisal (Sheppes & Meiran, 2007; Hermann et al., 2014). A growing number of studies are exploring top-down, guided attention as an emotion regulation strategy (Dolcos, Bogden at al., 2020; Dolcos, Katsumi et al., 2020; Moodie et al., 2020). Though earlier studies have directly compared cognitive reappraisal and guided attention (Robinson et al., 2021; Strauss et al., 2016), little research has evaluated the real-time interactions between working memory, attentional deployment, and affective response during implementation of cognitive reappraisal and guided attention. This study aims to expand this area of research.

Aim Two: Examining Temporal Effects of Top-down Emotion Regulation Strategies

Temporal effects can impact multiple aspects of emotion regulation (Adamczyk et al., 2022; Gross, 2002; Sheppes & Meiran, 2007; Sheppes & Gross, 2011; Dolcos, Bogden et al., 2020; Goldin et al., 2008). Specifically, high working memory load at onset of emotion regulation may be disruptive and delay cognitive reappraisal implementation (Adamczyk et al., 2022). Aim 2 of this study explores the effects of brief (4s) and sustained (8s) top-down emotion regulation strategy (i.e., guided attention and cognitive reappraisal) implementation on emotion regulation effectiveness (affect), working memory load (inter-trial change in pupil diameter), and attentional deployment (% of total trial fixations to AOI).

Interaction effects of time (4s, brief- or 8s, sustained-exposure) and top-down emotion regulation strategy (CR; GA) on emotion regulation effectiveness, working memory load, and attentional deployment (as described in Aim 1) will also be examined. Since there are no direct comparisons in prior research of the temporal effects (4s; 8s) of top-down emotion regulation strategies (i.e., cognitive reappraisal and guided attention) on emotion regulation effectiveness, working memory load, and attentional deployment, it can not be said with certainty what potential interaction effects between predictors and outcomes may occur. Therefore, in this study, the temporal effects of brief (4s) and sustained (8s) top-down emotion regulation strategy (i.e., guided attention and cognitive reappraisal) implementation on emotion regulation effectiveness, working memory load, and attentional deployment will be exploratory.

CHAPTER II:

METHODS

Participants

This study recruited participants (n = 54) with the main prerequisite of being older than 18, but no other demographic constraints, such as race or gender, were used. All procedures were conducted in compliance with the American Psychological Association Ethical Principles and were approved by the Committee for the Protection of Human Subjects Institutional Review Board at the University of Houston-Clear Lake (UHCL). All participants were screened to be free from visual or auditory impairments, or language barriers, which would prevent them from completing the experimental tasks. Participants with visual impairments were accepted if vision was corrected with eyeglasses or contact lenses. All participants were recruited from the UHCL SONA online participant pool and compensated 1.5 SONA credit hours for their time. Informed consent was obtained from all participants prior to the start of the study. Prior to the start of the study, all participants were offered a copy of the informed consent document and given a chance to ask questions about the study and their rights and responsibilities as a study participant.

The eye-tracking data of some participants was problematic; those participants (n = 16) were excluded from final analysis. One participant was excluded due to software malfunction (Inquisit 6), five participants were excluded due to hardware malfunctions, three participants were excluded due to corrective lens issues, five participants were excluded due to cosmetic-related issues, and two participants were excluded due to glare (n = 16). After these exclusions, 38 participants (n = 38, M_{age} = 27.24 years, SD_{age} = 9.89 years) were included in final analyses. Of the 38 participants remaining, approximately 82% were female, 15% male, and 3% gender non-conforming.

Participants identified as Asian (5%), African-American (13%), Hispanic or LatinX (42%), White (36%), and Mixed Race or Other (5%).

Materials

Participants viewed a total of 80 composite images with negative emotionally salient foregrounds (FG) and neutral backgrounds (BG). The images presented came from the Open Affective Standardized Image Set (OASIS) database (Kurdi et al., 2017), the Nencki Affective Picture System (NAPS) database (Marchewka et al., 2014), and the Geneva Affective Picture Database (Dan-Glauser & Scherer, 2011). Care was taken to select images of arousal and valence that elicited negative emotion without evoking extreme emotions like despair or terror ($M_{valence}$ = 30.54, $SD_{valence}$ = 13.41; $M_{arousal}$ = 53.15, $SD_{arousal}$ = 16.42) (*see Table 1*). The images were presented using Inquisit 6, a psychological experimentation application used to administer tasks over the web or on local devices. Room lighting and overall computer screen brightness were kept uniform during the experimental task. Brightness of images was varied.

Table 1

Image Valence & Arousal Matrix

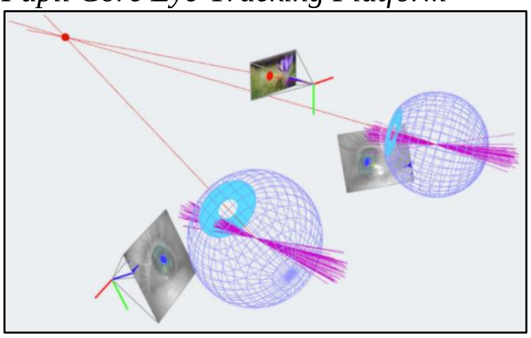
	Valence	***Arousal***
Mean	30.54	53.15
SD	13.41	16.42
Min	15.10	7.60
Max	49.30	30.48

Eye-Tracking Equipment

Open-source eye-tracking platform Pupil Core was used to measure gaze-based interaction with negative stimuli, as well as pupillometry and eye blinks. Pupil Core software and hardware includes an eye-tracking headset, open-source software for mobile eye-tracking, and graphical display to observe and visualize eye-tracking data (Kassner & Patera, 2012). Pupil Lab's corneal refraction measurement algorithm was used to measure inter-trial pupillary response. Pupil Core's algorithms and equipment provide accuracy of 0.08-degree precision at 0.6-degree of visual angle and processing latency of 0.045 seconds (Petersch & Dierkes, 2021). Pupil labs wearable eye-tracking hardware and open-source software provides high precision gaze mapping data (Macinnes et al., 2018).

Figure 1

Pupil Core Eye-Tracking Platform



Note. From *Pupil Labs* [Image], (https://pupil-labs.com/products/core/).

Measures

Eye-tracking was used to measure visual responses to negative emotionally salient stimuli. Participant gaze fixations and working memory responses (pupillometry and blink rate) were observed.

Pupillometry has often been used to effectively examine working memory load (Kahneman & Beatty, 1966; Beatty, 1982; Partala & Surakka, 2003; Steinhauer et al., 2004; van Der Wel & van Steenburgen, 2018; Strauss et al., 2016). Pupil dilation has also been linked to affective response, perception load, and shifts in lighting (Torres & Hout, 2019; Bradley et al., 2008), however pupil dilation has also been utilized as a measure of working memory load (Strauss et al., 2016; Kahneman & Beatty, 1966; van Reekum et al., 2007; Ochsner, Silvers & Buhle, 2012). An extensive review of pupil response by Mathôt (2018) points to the use of pupillometry as a measure of both cognitive effort and arousal in psychophysiological research. In this study, to control for arousal, the negative image set utilized was the same for all participants and on average was unrousing ($M_{arousal}$ = 53.15 out of 100) (*see Table 1*).

Eye blink rate (EBR) can be a reliable measure of working memory load and less susceptible to perceptual load than pupil dilation (Chen & Epps, 2014) and significantly linked to working memory load (Gavas et al., 2017; Siegle et al., 2008). EBR during cognitively rich tasks has been shown significantly higher than with low-cognitively demanding tasks, including when an auditory stimulus was used to pull resources from working memory (Magliacano et al., 2020). Though blink rates may differ based on individual differences, participants' blink rates can be standardized and utilized to observe cognitive load (Nomura & Maruno, 2019). In this study, EBR was utilized as a secondary working memory measure, and as a covariate measure of task fatigue.

Independent Variables

The independent variable of top-down emotion regulation strategy was operationalized as the implementation of either guided attention or cognitive reappraisal during viewing of negative emotionally salient stimuli. Temporal effects were defined by brief (4s) and sustained (8s) exposure times to negative emotionally salient stimuli. These brief and sustained image exposures were used to examine possible shifts in working memory load, attentional deployment, and emotion regulation effectiveness (i.e., affect) with longer exposure to negative emotionally salient stimuli. Brief exposure was operationalized as a 4s exposure to a negative emotionally salient image, and sustained exposure operationalized as an 8s exposure to a negative emotionally salient image.

Dependent Variables

Emotion Regulation Effectiveness

Emotion regulation effectiveness was operationalized by a 10-point mood scale of very negative (1) to very positive (10). Participants were asked to assess their mood immediately after viewing each image during the emotion regulation task. Affective responses were collected using a 10-point slider within the Inquisit 6 software during the top-down emotion regulation task. Higher affective response scores during the task were deemed indicative of better emotion regulation effectiveness, as higher responses indicated a more positive mood. It is important to note that participants were not asked to rate their perception of image negativity after viewing, but rather were asked to report their affective response to a negative image while implementing either top-down emotion regulation strategy of CR or GA.

Attentional Deployment

The dependent variable of attentional deployment was operationalized by the percentage of fixations on negative foregrounds over total screen fixations during negative image viewing. For example, for an image-viewing trial, if the participant had a total of 40 screen fixations during negative image viewing of which 10 are on the Area of Interest (AOI), that participant's Attentional Deployment to AOI for that trial would be 25% (i.e., 25% of total trial fixations to screen on negative stimuli).

$$\frac{\text{Fixations on AOI}}{\text{Total Fixations}}$$

Working Memory Load

In 1966, Kahneman and Beatty discovered that pupil dilation increased during a 7- vs 3-digit remembering task due to increases in working memory load. Pupil dilation has been routinely used as an index for working memory load (Baddeley, 2003; Beatty, 1982; Bradley et al., 2008; Fietz et al., 2022). A recent fMRI study examining working memory load and pupillary response during an N-back task corroborated that dilation is a reliable measure of working memory (Fietz et al., 2022).

For this study, the dependent variable of working memory load will be measured by inter-trial change in pupil diameter, operationalized by a proportion of pupil dilation change from baseline to trial. Mathôt and associates (2018) point to more overestimated pupil size due to blinks when subtractive baseline corrections are not made. For this reason, pupil diameter during baseline will be subtracted from pupil diameter during negative image viewing. Mathôt and associates (2018) also indicate that reporting change of subtractive baseline correction as a proportion is a minor variation that can be used for pupil dilation reporting. For example, in this study, if the participant's average trial pupil diameter is 38, compared to baseline diameter of 30, the inter-trial pupil change would be reported as 27% [i.e., (38-30)/30].

$$\frac{\text{Trial Pupil Diameter - Baseline Diameter}}{\text{Baseline Diameter}}$$

Baseline Corrections. Measuring pupil size without a comparison to baseline does not consider differences in pupil size within and between subjects. A baseline correction can be performed by examining pupil changes versus sizes, reducing noise, and increasing power. Corrective baseline measures are less affected by distortions such as baseline period pupil size recording errors, which can occur due to eye blinks, data loss, or other distortions (Mathôt et al., 2018).

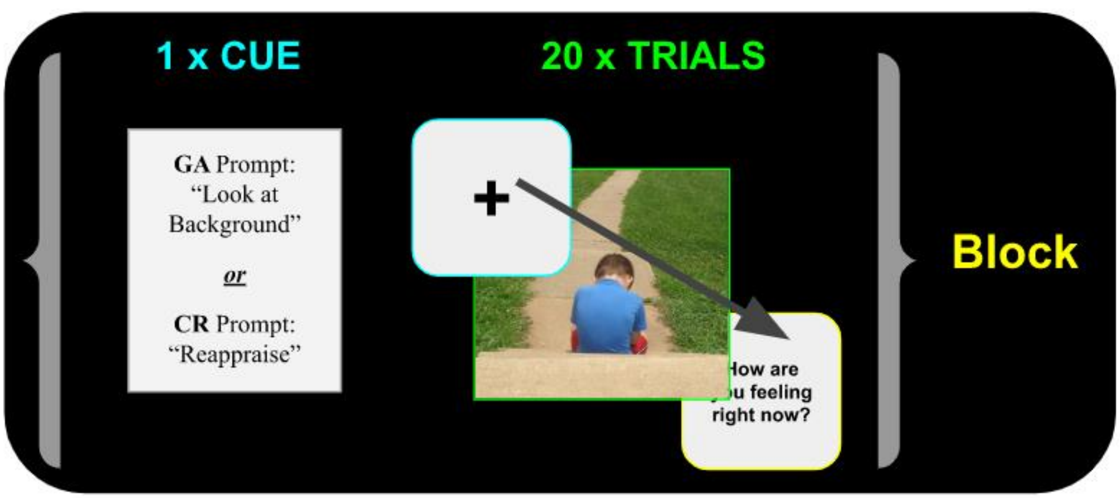
Eye-blink Corrections. Before calculating inter-trial pupil diameter change, zero values were removed when averaging the pupil dilation for each trial, as zeros indicate data loss or blinks (Mathôt et al., 2018).

Top-Down Emotional Regulation Task Design

Participants were presented with an emotion regulation strategy cue that directs the participant to cognitively reappraise (i.e., "Reappraise") or to use guided attention (i.e., "Background"). The participants were then shown, for 4 or 8 seconds, an image with an emotionally salient foreground and neutral background. Participants were able to freely view the images. Following the display of each image, participants were presented with a subjective emotional experience measure, by way of a 10-point slider that ranges from very negative (1) to very positive (10). All responses were made using a computer screen and mouse. A schematic of the task design is provided in Figure 2.

Figure 2

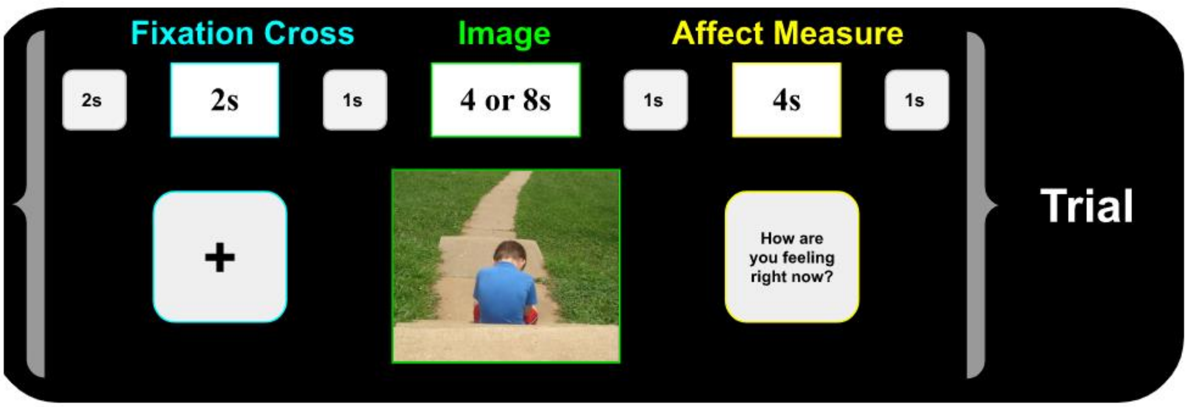
Repeated-Measures Task Diagram



Participants viewed a total of 80 images in the experimental task: 20 images under each of the two, top-down emotion regulation manipulation conditions and exposure times (i.e., 20 images with 4s of guided attention, 20 images with 8s of guided attention, 20 images with 4s of cognitive reappraisal, 20 images with 8s of cognitive reappraisal). The 80 images were divided into four blocks of 20 images each. Images for each block were randomized. Within each block, negative image exposure times (4s; 8s) were randomized. A schematic of the trial design is provided in Figure 3.

Figure 3

Trial Diagram



Procedures

Prior to image viewing in the top-down emotion regulation task, participants were administered self-report questionnaires via Qualtrics, then instructed on how to implement the two top-down emotion regulation strategies (i.e., cognitive reappraisal and guided attention) using a pre-made instructional video. Following the video, participants were asked if they had questions on how to implement the emotion regulation strategies before starting the task. Care was also taken to not over-teach emotion regulation strategy implementation.

After emotion-regulation strategy training, participants were given instructions on the top-down emotion regulation experimental task:

"You will complete an image viewing task during which you will implement the two emotion regulation strategies of guided attention and cognitive reappraisal while viewing images. During the image-viewing task, there will be four sets of 20 images. Before each set of images, the instructions "Reappraise" or "Look at Background" will appear. Make sure to use the appropriate emotion regulation strategy for each instruction and use the same strategy for all images in the set…. After viewing each image, there will be a slider to record your mood. Simply click on a point in the mood scale that best matches your feelings at the time."

After task instructions, participants were fitted with the Pupil Labs eye-tracking equipment and eye tracking calibration was performed. Once calibration was reached, the top-down emotion regulation task was administered, during which eye-tracking data was collected.

CHAPTER III:

RESULTS

Data Processing

RStudio statistical software was used to clean, visualize, and examine all data (RStudio Team, 2020; Lüdecke et al., 2021). Individual trials with missing data values were removed.

Outlier Detection

After removal of missing data, outlier detection was conducted using an application of the IQR method using the following formula:

$$IQR = Q3 - Q1$$

$$\text{Lower Bound: } (Q1 - 1.5 * IQR)$$

$$\text{Upper Bound: } (Q3 + 1.5 * IQR)$$

The scale of 1.5 was used to identify any data point less than the lower bound or more than the upper bound as an outlier. The IQR method resulted in the removal of 45 eye-tracking values and 43 trials.

Assumptions

Two-way, repeated-measures ANOVA inferential statistical procedure was used to separately examine effects of strategy (guided attention vs cognitive reappraisal), time (brief, 4s vs sustained, 8s), and strategy by time interactions on emotion regulation effectiveness (self-reported affect), working memory load (inter-trial change in pupil diameter), and attentional deployment (% of total trial fixations on AOI). Prior to implementing the ANOVA procedures, visual analysis of the distribution of outcome variables was observed using Q-Q plots. Working memory load was observed to exhibit normal distribution, however affective response scores and attentional deployment to AOI were problematic.

Shapiro-Wilk test of normality was performed and revealed that affective response and attentional deployment to AOI departed from normality (W = 0.95, p-value < 0.01 and W = 0.80, p-value < 0.01, respectively). However, repeated-measures ANOVA results are considered relatively robust against violations of normality assumptions if sample sizes are adequate. In addition, when homogeneity of variance assumptions for all dependent variables are not met, a stricter alpha level (i.e., .001 vs. .05) can be used to evaluate ANOVA results (Allen & Bennett, 2008). All significant ANOVA results in this study met a stricter alpha level guideline ($p < .001$), except for strategy's effect on working memory load (*see Table 3*). Since there were not more than two levels in the analysis, the assumption of sphericity was already met (Field et al., 2012). Finally, each observation was independent of one another in the study.

Repeated-Measures ANOVA Results

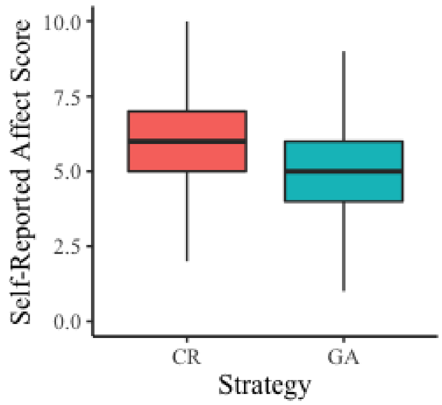
Repeated measures ANOVA inferential statistical procedure was used to examine the effects of time, strategy, and time by strategy interactions on the dependent variables of emotion regulation effectiveness, working memory load, and attentional deployment.

Emotion Regulation Effectiveness

A 2 (strategy) by 2 (time) ANOVA was conducted with emotion regulation effectiveness (affect) as the dependent variable. The main effect of strategy was significant, $F(1, 37) = 14.30$, $p < .001$, indicating that affective response was influenced by strategy (CR; GA) (*see Table 2*). Post-hoc analysis revealed that average affective response - on a mood scale of 1 (very bad) to 10 (very good) - was slightly above neutral across trials (CR 4s; CR 8s; GA 4s; GA 8s) ($M = 5.57$; $SE = 0.03$), with most responses falling in neutral to positive range. Both strategies did maintain emotion regulation effectiveness (score > 5 on a 1-10 self-reported mood scale) (*see Figure 4*). On average, CR led to a more positive affective response during trials (*M* = 5.83; *SE* = 0.23), compared to GA (*M* = 5.31; *SE* = 0.19, *t*(37) = 3.78, *p* < .001.

Figure 4

Affective Response by Strategy



A main effect of time was not observed (*see Table 2*), alluding to the effectiveness of top-down emotion regulation (CR & GA) regardless of brief (4s) or sustained (8s) exposure to negative stimuli (*F*(1, 37) = 2.364, *p* = .133). Post-hoc results show that brief (4s) (*M* = 5.568, *SE* = .047) and sustained (8s) (*M* = 5.569, *SE* = .048 negative image trials had similar affective responses (*See Figure 5*).

Interactions were not observed for strategy by time on emotion regulation effectiveness (self-reported affect) (*F*(1, 37) = 0.210, *p* > .05) or on working memory (inter-trial change in pupil diameter) (*F*(1, 37) = 0.001, *p* > .05) (*see Table 2*).

Figure 5

Affective Response by Time

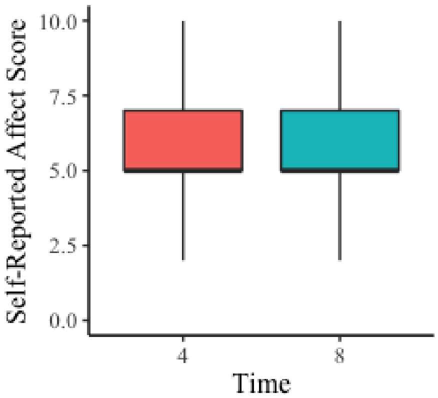


Table 2

ANOVA Results—Emotion Regulation Effectiveness

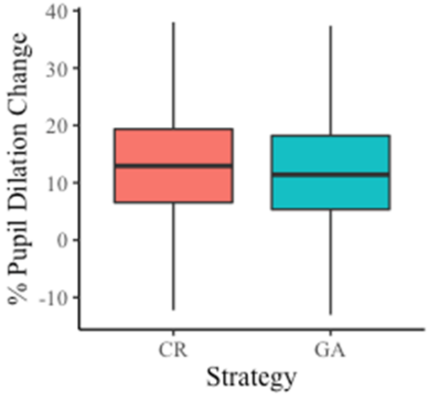
Dependent Variable: **Affect**	***SS_n***	***SS_d***	***F***	***p***
Strategy	10.303	26.66	14.296	.001**
Time	0.157	2.455	2.364	0.133
Strategy by Time	0.016	2.832	0.210	0.650

Working Memory Load

A 2 (strategy) by 2 (time) ANOVA was conducted with working memory load (inter-trial change in pupil dilation) as the dependent variable. The main effect of strategy was not significant when utilizing the more stringent criteria of a significance at $p < .001$ ($F(1, 37) = 4.80$, $p = .035$) (*see Table 3*, *Figure 6*). In addition, mean pupil dilation during all trials (CR 4s; CR 8s; GA 4s; GA 8s) was significantly higher ($M = 31.38$, $SE = 0.98$) than average pupil dilation at baseline (before trials) ($M = 27.95$, $SE = 0.919$) ($t(37) = 13.00$, $p < .001$) with a very large effect size ($d = 2.11$).

Figure 6

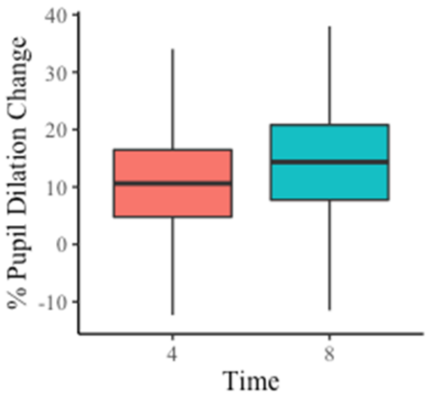
Working Memory Load by Strategy



A main effect of time was observed for longer duration (8s) top-down emotion regulation compared to brief duration (4s) (F(1, 37) = 68.48, p < .001) (*see Table 3, Figure 7*). Post-hoc analysis revealed that sustained (8s) (*M = 14.36, SE = .25*) top-down emotion regulation was more cognitively effortful (as measured by inter-trial pupil dilation) than brief (4s) (*M = 10.91, SE = .22*) top-down emotion regulation, t(37) = -8.28, p < .001.

Figure 7

Working Memory Load by Time



Interactions were not observed for strategy by time on working memory (inter-trial change in pupil diameter) ($F(1, 37) = 0.001$, $p > .05$) (*see Table 3*).

Table 3

ANOVA Results — Working Memory

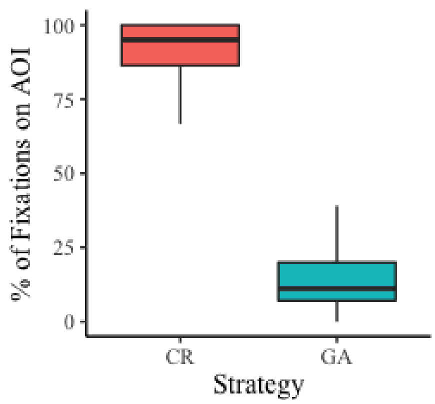
Dependent Variable: **Working Memory Load**	SS_n	SS_d	*F*	*p*
Strategy	52.884	407.637	4.800	.035
Time	429.119	231.841	68.484	< .001***
Strategy by Time	0.003	91.408	0.001	0.973

Attentional Deployment

A 2 (strategy) by 2 (time) ANOVA was conducted with attentional deployment (% trial fixations on AOI) as the dependent variable. The main effect of strategy was significant, ($F(1, 37) = 1{,}972.02$, $p < .001$), indicating that emotion regulation strategy (CR; GA) significantly influenced attentional deployment (*see Table 5, Figure 8*). Post-hoc results indicate that during trials, CR resulted in substantially greater fixations to negative AOIs ($M = 90.29$, $SE = .36$) compared to GA ($M = 17.85$, $SE = .50$), $t(37) = 44.4$, $p < .001$.

Figure 8

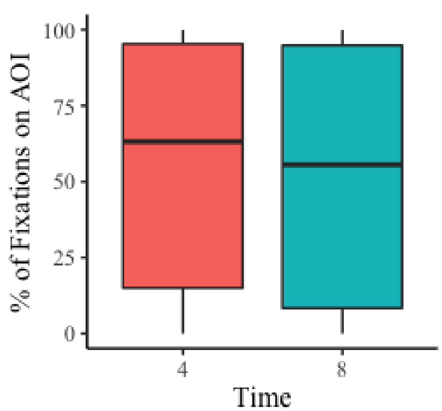
Attentional Deployment by Strategy



The main effect of time was significant, ($F(1, 37) = 15.81$, $p < .001$), indicating that time (4s; 8s) significantly influenced attentional deployment (% trial fixations on AOI) (*see Table 5*, *Figure 9*). Post-hoc results indicated that brief (4s) emotion regulation elicits slightly higher attentional deployment to AOI than does sustained (8s) emotion regulation (M_{4s}= 55.84, SD_{4s} = 38.68; M_{8s} = 51.94, SE_{8s} = 41.14), $t(37) = 3.98$, $p < .001$.

Figure 9

Attentional Deployment by Time



In fact, separate regression analyses (*see Table 4*) revealed that when measuring sustained (8s) vs brief (4s) trials effects on total fixations to AOI, rather than as a percent of total fixations to AOIs, moving from 4s to 8s trials resulted in an increase of total fixations to AOI by 18.57 fixations ($\beta = 18.57$, $p < .001$), yet emotion regulation effectiveness (affect) was not significantly changed from brief (4s) to sustained (8s) top-down emotion regulation strategy implementation ($\beta = 0.00$, $p > .05$).

Table 4

Time by Total Fixations and by Affect

	Total Fixations		
Predictors	*Estimates*	*std. Error*	*p*
Time	18.57 ***	0.12	<0.001
Observations	2995		
R^2 / R^2 adjusted	0.891 / 0.891		

* *p<0.05* ** *p<0.01* *** *p<0.001*

	Affective Response		
Predictors	*Estimates*	*std. Error*	*p*
Time	0.00	0.07	0.996
Observations	2995		
R^2 / R^2 adjusted	0.000 / -0.000		

* *p<0.05* ** *p<0.01* *** *p<0.001*

An interaction was observed for strategy by time on attentional deployment to AOI ($F(1, 37) = 54.28$, $p < .001$) (*see Table 5*). A post-hoc multiple linear regression revealed that CR (vs GA) decreased attentional deployment to AOI by 68.50% ($p < .001$) and strategy by time interactions decreased attentional deployment to AOI by 7.99% ($p < .001$) when controlling for time ($R^2 = 0.83$, $F(3, 2991) = 4751$, $p < .001$).

Table 5

ANOVA Results — Attentional Deployments

Dependent Variable: **Attentional Deployment**	***SS_n***	***SS_d***	***F***	***p***
Strategy	199731.3	3747.463	1972.016	<.001***
Time	300.328	702.716	15.813	< .001***
Strategy by Time	662.119	451.320	54.282	< .001***

It is important to note that the distribution of the data for attentional deployment (% of total trial fixations on AOI) was non-parametric. Due to issues with data loss during eye-tracking, several participants' eye-tracking data could not be used for analysis. A more stringent data significance was used to analyze results ($p < .001$), however, to say with full confidence that no Type I error occurred in attentional deployment results, a larger sample size would be needed. Given a larger sample size, a 2-way ANOVA statistical procedure's results could be relied upon. Upon visualizing the attentional deployment data (*see Figure 8*), strategy does have a clear difference in AOI fixations compared to GA and with minimal data variability. However, upon examining AOI fixations by time (4s; 8s), succinct differences are not observed, and variability is high (*see Figure 9*). To best understand effects of time and time by strategy interactions on attentional deployment, non-parametric analyses would be more reliable.

CHAPTER IV:

DISCUSSION

The primary purpose of this study was to examine the effects of the two prevailing top-down emotion regulation strategies (CR; GA) on emotion regulation effectiveness, working memory load, and attentional deployment behavior. The top-down strategy of cognitive reappraisal has been extensively compared to bottom-up strategies, such as passive viewing or suppression (Strauss et al., 2016; Gross, 1998; Gross & Thompson, 2007; Blumberg, Rice & Dickmeis, 2016). More recent studies have begun to directly compare the two prevailing top-down emotion regulation strategies of cognitive reappraisal and guided attention (Moodie et al., 2020; Robinson et al, 2021). Examining the temporal effects of top-down strategies adds yet more dimension to outcomes (Adamczyk et al., 2022; Gross, 2002; Sheppes & Meiran, 2007; Goldin et al., 2008). Human emotions are complex. This exploratory study's findings help add to the ever-growing body of work of understanding the intricacies of human emotion.

Principal Findings

In line with earlier research, results of this study show that top-down emotion regulation strategies are effective at regulating emotion (Sheppes & Meiran, 2007; Dolcos, Bogdan et al., 2020). When directly comparing CR to GA, CR was more effective than GA at regulating emotion. GA affective response averages were near neutral, while CR responses were slightly more positive.

During trials, CR resulted in a substantially greater attentional deployment to AOIs. This pronounced difference in attentional deployment for CR may have been due to marked distinction between participant eye gaze patterns during CR (vs GA). During CR, most participants attended to negative AOIs without avoidance, while GA usually averted attention away from stimuli. Research by van Reekum and colleagues (2007) points to construction of a narrative during cognitive reappraisal as reasoning for the increased AOI fixations.

The effectiveness of CR as an emotion regulation strategy is more pronounced when considering AOI fixations were significantly greater for CR (vs GA), resulting in more visual attention to negative stimuli. Affective response was also similar for 4s and 8s trials, pointing to top-down emotion regulation's effectiveness at maintaining emotion regulation for up to 8 seconds of exposure to negative stimuli. The finding that CR resulted in both significantly higher AOI fixation and more positive affective response than GA further underlines the effectiveness of CR as an emotion regulation strategy. However, this finding should be interpreted with a caveat that attentional deployment distribution was non-parametric in this study.

Attentional deployment, and emotion regulation effectiveness seem to be impacted by strategy (CR, GA), time (4s, 8s) and/or strategy by time interactions. This study's findings help add to the more dynamic picture of the temporal effects of top-down emotion regulation on attentional deployment and affective response.

Limitations & Future Directions

A primary limitation of the study arose when analyzing and interpreting the results of the measure of attentional deployment. Due to the pronounced difference in eye gaze fixations to (CR) and away from (GA) AOI, the attentional deployment results had a non-parametric distribution. Given limits in sample size, a 2-way ANOVA statistical procedure's results could not be relied upon, outside of the results of strategy on attentional deployment, which were verified using data visualization. To best understand effects of time and time by strategy (CR; GA) interactions on attentional deployment, future studies should plan to conduct non-parametric analyses that can ensure results do not succumb to potential Type I error.

After experimentation began, it was observed that some images were problematic in providing a clear “background” area for GA eye gaze to AOI. Some AOIs that had a large, solid color block, though technically on the AOI, may have been considered “background” for participants attempting to avert gaze to backgrounds. For example, if a participant fixated on a small part of a foreground, subjectively that foreground may have become a non-AOI background. Future studies may wish to place great care to select an image set with clearly defined backgrounds and foregrounds for each image. Clearly defined background-foreground areas could help better discern whether a participant was looking back (ruminating) on AOI areas rather than simply searching for a background on which to focus for guided attention implementation.

Pupil dilation can be considered a reliable marker of working memory load, even after controlling for pupil dilation shifts due to perceptual and affective response. Pupillometry has been utilized in multiple studies to operationalize working memory load (Kahneman & Beatty, 1966; Ochsner et al., 2012; Strauss et al., 2016; van Reekum et al., 2007). Though no major changes in room lighting occurred from pupil dilations measurements at baseline and image trials, images used in this study had emotional content and varied by brightness compared to baseline (white background with centered black cross). Increased pupil dilation could have occurred because of confounding factors rather than top-down emotion regulation implementation. Though top-down emotion regulation strategy implementation has been shown to increase working memory compared to bottom-up (Strauss et al., 2016; Adamczyk et al., 2022; Fietz et al., 2022), a side-by-side comparisons of top-down emotion regulation with bottom-up passive viewing would ensure a more standardized baseline measure for bottom-up emotion regulation to bottom-up passive viewing.

When evaluating covariates, heightened positive emotional state, as well as negative emotional state was later linked to higher affective response during emotion regulation. Perhaps this result is an indicator that emotional state prior to emotion regulation activation influences the degree to which emotion regulation is activated. Future research may further examine why heightened emotional state – positive or negative – significantly impacted effects of emotion regulation. Surprisingly, respondents' tendencies to regulate emotions using reappraisal (PSQ) was not significant in the model (Gross & John, 2003). Though care was taken to not over-train, this result may be due to successful emotion regulation strategy training (CR; GA) prior to the start of the experiment. To better understand the role of a participant's emotion regulation tendency, future studies may consider examining effects of top-down emotion regulation without reappraisal training, as implementation of cognitive reappraisal might be trained relatively easily, at least for short term use. In fact, top-down emotion regulation training could be a useful and effective tool for short term emotion regulation.

Future researchers may also consider further examining the covariate factors of childhood experience on divergent emotion regulation. Prior research shows that response to negative stimuli for maltreated and non-maltreated youth is modulated similarly in the amygdala, but for maltreated youth, this response is at a cost of greater recruitment of brain areas implicated in cognitive control (McLaughlin et al., 2015). This study did find that parenting style did influence affect and working memory response during emotion regulation. This points to the need for better understanding the role of development in the larger context of divergent outcomes on attention, affective response, and working memory load during emotion regulation.

Finally, an important finding of this study was that attention to stimuli may be a behavioral response indicative of implementing CR. Earlier it was stated that LPP amplitude increases during negative stimuli viewing and that when LPP and working memory load are high, cognitive reappraisal implementation can become thwarted (Adamczyk et al., 2022). Perhaps disruption to reappraisal implementation when LPP and working memory load are both high may be in part influenced by visual attendance to stimuli during CR implementation. CR implementation seems to be fueled by using stimuli - negative or positive - to reframe meaning. To reframe stimuli context using reappraisal, internal verbal behavior, as well as visual attendance, was needed to "reappraise" the negative stimuli into a more positive meaning. In fact, inner speech can play an active role in cognitive reappraisal implementation, regardless of emotion regulation effectiveness (Salas et al., 2018). Inner verbal behavior can even have a negative reappraising effect and exacerbate a situation from a neutral to a more negative context (McLaughlin et al., 2016). Given research by van Reekum and colleagues (2007) point to the use of AOI to potentially construct a narrative during cognitive reappraisal, future studies may further examine the interplay between attentional deployment and affective response in emotion regulation.

Conclusion

It is ideal to function through life from a place where more efficient top-down strategies for emotion regulation are utilized, when possible. The potential interactions of emotion regulation and working memory are more pronounced when individual differences are considered (Scheibe & Blanchard-Fields, 2009; Garrison & Schmeichel, 2022; Schmeichel & Tang, 2015). Additional research is needed to gain a more intricate understanding of divergent online emotion regulation efforts on the interplay between attention, affect, and working memory load. Seeking out a more dynamic understanding of human emotion regulation is important considering that some groups, such as single mothers or low-income individuals, may be more susceptible to prolonged working memory load (Rutherford et al., 2016; Baumeister et al., 1998; Cowan, 2013) or attentional biases (Greimel et al., 2020; Barry et al., 2015; Wieser & Keil, 2020) that impact emotion regulation. Given that cognitive reappraisal implementation may be hindered if working memory load is high, potentially due to a neural shared-space for AOI processing, care must be taken to better understand how working memory load may leave the effective emotion regulation strategy of cognitive reappraisal less accessible for some. Additional research of online emotion regulation could help bring forth translational research that ensures people from divergent backgrounds have equal access to effective emotion regulation.

Emotion regulation training techniques, like guided attention training (Dolcos, Bogdan, et al., 2020; Wadlinger & Isaacowitz, 2011), show a promising future and may help to aid those for whom learning other top-down emotion regulation strategies, such as reappraisal, has a steep learning curve (McLaughlin et al., 2015). Eye-gaze training may be a promising avenue to aid those for whom recruiting additional working memory resources needed for top-down reappraisal would be more costly. Gaining a better understanding of emotion regulation efforts and outcomes using the non-invasive, peripheral measure of eye gaze could lead to real-world applications that aid in both assessment and regulation of emotion using eye-tracking technology.

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