Role of memory processes in the emotion regulation of naturalistic events

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Regulating negative emotions that arise while recalling an unpleasant event presents a persistent challenge. As a reconstructive process, recall offers an opportunity to ease the burden of repeated regulation by updating negative memories, with the potential for long-term reductions in the negative affect associated with a memory. However, little is known about the recall-related brain processes that support lasting effects of emotion regulation on episodic memories. Across three studies, the current project examined the behavioral and neural correlates of regulating emotionally negative memories. First, a stimulus database of real-life news videos optimized for studying naturalistic emotional memory was developed. Then, the behavioral effects of two emotion regulation strategies, memory reappraisal and memory suppression, were tested. Finally, functional magnetic resonance imaging (fMRI) was used to investigate the brain processes associated with lasting reappraisal-related changes in memory valence. We found that reappraisal was associated with lasting reductions in the negative valence of naturalistic memories, whereas suppression had no effect on memory valence. We also found that recall-related activity in lateral occipital cortex was associated with a reappraisalmediated reduction in negative valence 24-hours after reappraisal. These results suggest that brain processes involved in the initial retrieval of negative content also support the emotion regulation of those memories, consistent with research showing that memory reactivation is critical for robust memory updating.

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INTRODUCTION

The ability to appropriately regulate emotions is critical for maintaining mental health (Gross and Muñoz 1995). However, the need to regulate one's emotions does not end once the emotion-triggering event is over. Rather, memories for emotional experiences are particularly enduring (Yonelinas and Ritchey 2015; Sheldon and Levine 2013; Christianson and Loftus 1990), and thus negative memories can create a persistent emotion regulation challenge. Accordingly, memory and affective symptoms are intertwined in many psychiatric disorders, including anxiety and depression (Elzinga and Bremner 2002; Nolen-Hoeksema et al. 2008; Harrington and Blankenship 2002; Aldao et al. 2010; Blalock and Joiner 2000; Holahan et al. 2005; Kashdan and Breen 2008) are related to mental health outcomes. Yet, though clinical psychology has long leveraged memory processes in order to analyze or explore past experiences (Luborsky 1977; Schafer 1980; Neshat-Doost et al. 2013; Moradi et al. 2014; Eigenhuis et al. 2017; van Minnen et al. 2002; Foa et al. 1995), little is known about the basic memory mechanisms involved in mediating successful long-term regulation of emotional episodic memories.

Several strategies might be used to regulate emotions arising from episodic memory, that is, memory for a specific event situated in a spatial and temporal context. One might try to forget, avoid, or suppress the memory, distract themselves, substitute a positive memory, or reinterpret the memory. One of the most widely studied strategies is cognitive reappraisal, which seeks to deliberately reinterpret and update a remembered experience to render it less emotionally negative (Holland and Kensinger 2013; Kross et al. 2009). Though the cognitive processes supporting the reappraisal of ongoing events have been extensively researched, the episodic memory mechanisms involved in facilitating successful *memory reappraisal*, the reappraisal of negative memories, are largely unknown. Here, I will briefly review two lines of research that shed light on the cognitive and neural mechanisms of memory modification: the extinction and

reconsolidation of fear associations and the reconstruction of episodic memories. Across both literatures, I conclude that memory reactivation plays a role in facilitating the kinds of longlasting memory changes that are likely to support successful memory reappraisal. Taking a novel perspective, I will consider memory reappraisal as a special case of memory modification that leverages reconstructive memory processes to alter emotional episodic memories.

Mechanisms of Emotional Memory Modification

In the context of emotion regulation, the goal of memory modification is to reduce the emotional impact of negative associations in memory. Two common ways to study the impact of emotion on memory, and its modification, are through measures of implicit memory for conditioned fear associations and measures of explicit, episodic memory for emotional events. Although distinct cognitive and neural processes are involved in expressing these forms of memories, research on fear conditioning has been used to inform our understanding of emotional episodic memory, and vice versa (Dunsmoor and Kroes 2019). Here, I review evidence from studies of conditioned fear associations that suggest that memory reactivation facilitates subsequent memory modification, and then relate these findings to current understanding of how we reconstruct and update emotional episodic memories.

Extinction and Reconsolidation of Conditioned Fear Memories

Conditioned fear memories are a type of associative memory that is formed when an aversive stimulus (UCS; unconditioned stimulus) is paired with a neutral stimulus (CS; conditioned stimulus), such that later presentation of the CS will evoke the fear response naturally associated with the UCS. Cued fear learning is supported by a circuit involving sensory regions, the amygdala (Dunn and Everitt 1988; LeDoux 2000), and regions involved in behavioral fear responses such as periaqueductal gray (Fanselow 1991). Contextual fear memories are additionally supported by the hippocampus (Rudy and O'Reilly 1999; Selden et al. 1991; Phillips

and LeDoux 1992). Functional magnetic resonance imaging (fMRI) suggests that the neural circuits underlying cued fear conditioning(LaBar et al. 1998; Büchel et al. 1998; Knight et al. 2004; Phelps et al. 2004; Cheng et al. 2003; Hermans et al. 2013) and contextual fear conditioning (Ji and Maren 2007; Alvarez et al. 2008; Lonsdorf et al. 2014; Marschner et al. 2008; Pohlack et al. 2012) are similar in rodents and humans. Thus, rodent models of conditioned fear can provide insight into fear memory processes in humans.

Once learned, fear memories are enduring and not generally vulnerable to forgetting (Gale et al. 2004; Rescorla and Heth 1975). However, there are two mechanisms through which fear memories can be updated to reduce the conditioned fear response: *extinction* and *reconsolidation* (Merlo et al. 2014). Extinction training seeks to reduce the conditioned fear response by repeatedly presenting the CS without the UCS so that the CS and UCS gradually become unpaired (Myers 2006), reducing fear responses to the CS in both rodents (Myers and Davis 2007) and humans (Quirk et al. 2010; LaBar et al. 1998; Phelps et al. 2004). However, though extinction training may reduce conditioned fear responses in the short-term, responses often return after time or when the CS is presented in a different context (Rescorla and Heth 1975). Thus, it seems that extinction training alone may not be sufficient for permanently modifying emotional memories.

Neuroscience research has provided compelling evidence that reactivating a fear memory before attempts at modification may be the key to a long-term reduction in conditioned fear responses. Rodent studies have suggested that protein synthesis processes necessary for *consolidation* into long-term memory (Hernandez and Abel 2008) can be leveraged after learning has already occurred, due to findings that memory reactivation triggers a process of reconsolidation that is similarly dependent on protein synthesis (Hupbach et al. 2013; Nadel et al. 2012). Indeed, disrupting protein synthesis using electroconvulsive therapy (ECT) (Misanin et al. 1968) or a protein synthesis inhibitor in rodents (Judge and Quartermain 1982; Nader et al. 2000) and humans (Kindt et al. 2009) has been shown to completely abolish fear responses only after the fear memory was reactivated, suggesting that reactivating the fear memory renders it labile and vulnerable to modification. Likewise, the principles of memory reactivation and reconsolidation have also been applied to boost the efficacy of extinction training, a behavioral intervention suitable for human use. Reactivating a fear memory before extinction training has been shown to permanently block the return of fear in rodents (Monfils et al. 2009) and humans (Schiller et al. 2010) though see (Kindt and Soeter 2013). Thus, reactivating a memory before extinction training may be a noninvasive method for reducing the expression of fear memories in humans (Beckers and Kindt 2017; Kindt and van Emmerik 2016; Elsey et al. 2018).

Updating of Emotional Episodic Memories

In contrast with conditioned fear memories, which can be expressed without recall of event details other than the cue-fear association, emotional episodic memories include information about spatial and temporal context, perceptual details, and mental states associated with a specific event (Tulving and Murray 1985; Tulving 1985). Retrieval of these detail-rich memories is supported by pattern completion operations of the hippocampus (Marr 1971), whereby an external or internal memory cue reactivates the rest of the memory trace, including its representation in cortical areas (Horner et al. 2015; Ritchey et al. 2013). For example, hearing a car horn might cause you to remember a car accident, including the location, weather, visual details of the damaged car, and associated fear.

As with fear memories, there is some evidence that episodic memories can be disrupted using techniques based on memory reactivation (Scully et al. 2017). One study showed that ECT, applied in patients with depression, was associated with reduced memory for an emotional story learned one week prior only if the memory had been reactivated before administration (Kroes et

al. 2014). There is also evidence that reactivation can weaken episodic memories if interfering information, like a story containing related or competing content, is introduced after reactivation (Kredlow and Otto 2015). For example, one recent study demonstrated that partially reactivating memories for aversive images before employing a spatial distancing emotion regulation strategy reduced associated emotional arousal more than reactivation alone (Parikh et al. 2019). Together, this suggests that reactivation serves a critical role in making episodic memories vulnerable to forgetting when neural processes are disrupted during the putative reconsolidation period.

While memory retrieval allows us to vividly relive past experiences, these details are not reactivated as a snapshot with perfect fidelity. Rather, memory is a reconstructive process (Schacter and Addis 2007) that allows for the flexible combination and recombination of memory details with other sources of knowledge (Addis et al. 2007). Importantly, as memories are reconstructed, memory errors may be made and new information can be introduced into memories (Pezdek et al. 2006; Desjardins and Scoboria 2007; Chan et al. 2009; Roediger et al. 1996). Although such reconstructive processing appears to be a ubiquitous characteristic of episodic memory retrieval, it also appears to be influenced by reactivation manipulations. It has been shown that reactivating a memory before learning new information causes the new information to be incorporated into the memory (Hupbach et al. 2009; Gershman et al. 2013; Hupbach et al. 2007; Hupbach et al. 2008; Chan and LaPaglia 2013). Although these findings sometimes have been attributed to the mechanisms of reconsolidation, other accounts have explained them in terms of contextual reinstatement and interference (Sederberg et al. 2011; Gershman et al. 2013), whereby memory reactivation increases the likelihood that new information will be associated with contextual features from the original event, modifying the expression of memory without requiring reconsolidation per se (Sederberg et al. 2011; Gershman et al. 2013). Finally, the degree of memory reactivation has also been proposed to

play a key role in competitive inhibition of associative memories, such that if memories or memory details are reactivated in competition with each other, the 'winning' memory trace is strengthened, whereas the 'losing' memory trace is weakened (Lewis-Peacock and Norman 2014) as long as it was at least moderately reactivated (Ritvo et al. 2019). Thus, reactivation and reconstructive processes support the incorporation of new information in memory, raising the possibility that emotion regulation strategies can leverage these processes to introduce information that will modify emotional memories to be less negative.

Cognitive Reappraisal as a Special Case of Memory Modification

Cognitive reappraisal, though not often considered as a memory modification process, has been repeatedly shown to be a healthy and effective strategy to reduce negative affect during an unpleasant situation (Gross 1998; Richards and Gross 2000; Gross and John 2003). This strategy involves deliberately reframing an ongoing event or memory ('memory' reappraisal) by reinterpreting the experience (Wager et al. 2008; Ochsner et al. 2002; Ochsner et al. 2004), focusing on a positive outcome (Baker et al. 2017), or finding a 'silver lining' (Holland and Kensinger 2013; Troy et al. 2010). For example, if recalling a car accident, one might focus on the fact that no one was seriously injured, or that the frightening experience brought their family closer together. When used habitually, reappraisal may protect against fear learning (Hermann et al. 2014). Basic reappraisal has also been proven effective in clinical settings (Sloan and Telch 2002). Over time, training in reappraisal has also been shown to reduce negative affect while viewing aversive images (Denny and Ochsner 2014), self-reported depression (Morris et al. 2015), and perceived stress (Denny and Ochsner 2014). In addition, some studies have found that memory reappraisal can be an effective way to reduce emotionality while remembering a negative event. For example, participants were cued to recall specific autobiographical memories (Holland and Kensinger 2013) or aversive images (Holland and

Kensinger 2013) using self-generated memory titles. Self-reported negative affect during remembering was reduced by instructions to decrease emotion using memory reappraisal compared to instructions to maintain emotion. Importantly, one study also found that the effects of memory reappraisal can persist after the reappraisal period, such that autobiographical memories that had been reappraised were rated as less negatively valenced when recalled again after a 30-minute delay (Holland and Kensinger 2013). However, it is not yet well understood what factors determine whether or not memory reappraisal will modify memories in a lasting way, such that they carry less emotional significance or elicit a less intense emotional reaction when remembered again in the future.



Figure 1. Schematic of reappraisal as memory updating process. When a memory is cued, the memory representation is reactivated via pattern completion processes mediated by the hippocampus. The reactivated memory representation then becomes labile, allowing retrospective reappraisal to introduce new information that reduces negative emotionality. The updated memory is then reconsolidated so that the trace containing the reappraisal, associated with reduced emotionality, is later retrieved.

We propose that one way in which memory reappraisal differs from the reappraisal of ongoing events is in its reliance on memory reactivation and reconstruction processes to reduce the negative impact of emotional episodic memories (Figure 1). During memory reappraisal, the details of a cued negative memory first must be reactivated in order to be re-interpreted. A possible byproduct of this reactivation is that it renders the memory labile and thus able to be successfully updated (Hupbach et al. 2013; Nadel et al. 2012). New information (the reappraisal) is then introduced to make the memory less emotionally impactful, a process that is mediated by control regions such as ventral and dorsal prefrontal cortex and dorsal anterior cingulate cortex (Holland and Kensinger 2013; Holland and Kensinger 2013). After the reappraisal has been completed, the memory can be reconsolidated with the updated information, so that this new information will be retrieved the next time the memory is cued. Importantly, because episodic memories contain multiple details and associations, we hypothesize that the completeness, or strength, of reactivation prior to reappraisal should be related to the likelihood of successfully updating the episodic memory. This may involve overwriting the memory, in the case of reconsolidation, or making it more likely that future memory cues will activate the reappraised version of the memory. In contrast, partial reactivation of some components of memory-- such as defensive responses or subjective feelings (Phelps and Hofmann 2019)-- without the corresponding episodic details may be insufficient to fully update the event representation. Although the extant literature points to the importance of reactivation prior to memory updating, reappraisal itself may elicit further memory reactivation as details are elaborated and reinterpreted. Thus, it remains an open question at what point during the reappraisal process the degree of reactivation is most important for regulation success.

In contrast to the beneficial effects of reappraisal, there is some evidence that emotion regulation strategies that avoid detailed memory reactivation are relatively ineffective at 8

reducing negative affect. For example, suppressing emotional responses (emotion suppression) during remembering can actually increase negative affect in people with high negative trait affect (Dalgleish et al. 2009). Furthermore, avoiding unpleasant cognitive or internal experiences is positively related to an increase in anxiety (Blalock and Joiner 2000), depressive symptoms (Holahan et al. 2005; Blalock and Joiner 2000), and PTSD symptoms (Boeschen et al. 2001), suggesting that suppressive strategies may be broadly related to negative mental health outcomes. Additionally, though there is some evidence that explicit attempts to suppress memories (*memory suppression*) may reduce their accessibility (Anderson and Green 2001; Depue et al. 2007; Depue et al. 2006), other studies have reported a rebound effect in which suppressing distressing autobiographical memories actually increases the number of later memory intrusions (Geraerts et al. 2006). Because memory suppression occurs in response to partial reactivation of the memory but avoids any further reactivation of episodic details, its inhibitory influence may influence the accessibility of the memory without updating its contents. By comparison, online reappraisal seems to maintain (Dillon and Pizzagalli 2013) or even improve memory for reappraised events (Dillon et al. 2007), while also reducing the emotionality of the memory (Holland and Kensinger 2013; Holland and Kensinger 2013). Additional work is needed to further investigate the effect of employing different regulation strategies during recall on the details, subjective feelings, and defensive responses (Phelps and Hofmann 2019) associated with emotional memories. Based on the reviewed evidence, we expect that strategies that strongly reactivate episodic details in memory, such as memory reappraisal, may be more effective at reducing negative affect and better at promoting adaptive learning compared to strategies that limit memory reactivation. Additionally, a memory updating process that leaves important details intact but decreases emotional impact during later remembering may be an effective and adaptive approach to coping with emotional memories. Moreover, effective regulation must be robust to strong retrieval cues that can access weakened or suppressed memories, as complex episodic memories are unlikely to be entirely forgotten

(Tulving 1974). Because memory reappraisal involves elaborate memory retrieval, and retrieval enhances memory retention (Nungester and Duchastel 1982; Roediger and Karpicke 2006; Roediger and Butler 2011), it is likely that memory reappraisal maintains adaptive emotional memories even if the emotional impact is reduced, making it an optimal emotion regulation strategy to employ during recall.

CURRENT DIRECTIONS

The research discussed above suggests that memory reappraisal may leverage reconstructive episodic memory processes to successfully downregulate negative affect. However, because existing studies of cognitive reappraisal vary considerably in their specific reappraisal instructions, times of regulation and testing (i.e., during encoding, retrieval), types of stimuli (e.g., autobiographical memories, still images, videos), and dependent variables (e.g., memory valence, emotional intensity), further work is necessary to establish the long-term efficacy of different applications of memory reappraisal. In particular, questions regarding the memory mechanisms underlying the emotion regulation of memories remain. For example, do memory reappraisal and memory suppression have converging or differing effects on memory emotionality and accuracy? If memory reappraisal does indeed reduce the emotionality of unpleasant memories, is reappraisal success supported by memory reactivation? And if so, what is the nature of the relationship between reactivation strength and reappraisal success? Across three studies, I will consider memory reappraisal as a special case of memory modification that leverages reconstructive processes to alter emotional episodic memories. First, I will describe a database of naturalistic stimuli optimized for studying emotional memory, then I will report the effects of memory reappraisal and memory suppression on memory emotionality and accessibility, and finally I will use fMRI to explore the relationship between memory reactivation and reappraisal success.

1.0 A DATABASE OF NEWS VIDEOS FOR INVESTIGATING THE DYNAMICS OF EMOTION AND MEMORY

Rosalie Samide, Rose Cooper, & Maureen Ritchey Behavior Research Methods (2019)

1.1 OVERVIEW

Emotional experiences are known to be both perceived (for review see Zadra and Clore 2011) and remembered (for review see Kensinger 2009; Yonelinas and Ritchey 2015) differently from non-emotional experiences, often leading to heightened encoding of salient visual details (Kensinger et al. 2007) and subjectively vivid recollection (for review see Phelps and Sharot 2008). The majority of previous studies has used static images (e.g., Lang et al. 2008; Marchewka et al. 2014) to investigate how emotional event content modulates cognition, yet natural events unfold over time. Therefore, little is known about how emotion dynamically modulates continuous experience. While there are several databases of temporally dynamic stimuli, these existing stimuli datasets have some limitations, which have motivated the current project. First, film clips taken from movies (Chen et al. 2017; Soleymani et al. 2012; Schaefer et al. 2010), television shows, or music videos (Koelstra et al. 2012; Abadi et al. 2015) may be processed differently than autobiographical events because participants are aware that the events depicted are fictional (Abraham et al., 2008). Video clips taken from popular media like movies and television may also be familiar to some participants, which can affect memory (Wilson and Rolls 1993; Tulving et al. 1996) and emotional processing (Ishai et al. 2004). Thus, when the possibility of familiarity exists, a measure of stimulus familiarity is necessary for the interpretation of memory or emotion results. Additionally, though other video databases have measured emotion, this has typically been rated over short segments, thus averaging over a

subsection of the full-length stimulus. A dynamic or continuous measure of participants' emotional experiences while watching stimuli would be useful for future experiments. Here, we report a norming study wherein we develop a new stimulus set of 126 emotionally negative, positive, and neutral videos depicting real-life news events. Participants continuously rated the valence of each video during its presentation and judged the overall emotional intensity and valence at the end of each video. In a subsequent memory test, participants reported how vividly they could recall the video details and estimated each video's duration. We report data on the affective qualities and subjective memorability of each video. The results replicate the well-established effect that emotional experiences are more vividly remembered than nonemotional experiences. Importantly, this novel stimulus set will facilitate research into the temporal dynamics of emotional processing and memory.

1.2 METHODS

1.2.1 Participants

A total of 100 participants (69 females, 31 males) took part in the current experiment, with 50 participants rating each video. Sample size was determined a priori to be somewhat larger than those used in other studies reporting normative data from video stimuli. For example, the MAHNOB-HCI database (Soleymani et al. 2012) reports data from 27 subjects, the DEAP database (Koelstra et al. 2012) reports data from 32, and the DECAF database (Abadi et al. 2015) from 30. Our sample size was chosen before data collection with the goal of collecting enough normative data to allow researchers to bin videos into negative, neutral, and positive categories for their own experiments. With emotional materials, however, there are often individual differences in participants' affective responses to the stimuli, and thus, we also encourage researchers to collect normative ratings from their own sample to confirm category

assignment, especially for participants drawn from populations with different characteristics to those reported here. All participants were between the ages of 18 and 22 (mean = 19.01, SD = 0.85), had normal or corrected-to-normal vision, and had no current diagnoses or history of psychological or neurological disorders. Informed consent was obtained from all participants. All procedures were approved by the Boston College Institutional Review Board, and participants received course credit for their time.

1.2.2 Materials

The videos were gathered from a television news archive found at https://archive.org/details/tv. Videos were downloaded based on searches for keywords or phrases in the transcript. To get a range of negative videos, keywords included words such as 'disaster', 'murder', 'poverty', 'victim', and 'tragic'. Neutral videos including words such as 'weather', 'traffic', 'school', 'construction', and 'business', and positive videos were found with words including 'happy', 'celebration', 'heartwarming', 'surprise', and 'uplifting'. These videos were then manually filtered to remove any with low quality resolution, any containing an event similar to other videos, and any reporting highly familiar, international news stories. Videos containing only a verbal description of the event were also excluded; thus, the remaining videos all contained some visual footage of the event. This process resulted in a total of 144 videos that were selected to be used in the norming experiment, 48 of which came from negative keywords, 48 from neutral keywords, and 48 from positive keywords, based on keyword valence judged by the experimenters. All videos were trimmed to be between 20 and 52 seconds in duration and to remove any footage at the beginning or end that did not pertain to the central news story. The mean duration was 42.15 seconds (SD = 7.70). All videos were 640 pixels in width and between 360 and 480 pixels in height.



Figure 2. Task design. During the Viewing Phase, participants watched news video clips while continuously rating pleasantness. After each clip, they then rated summary pleasantness (valence), emotional intensity, familiarity with the story, and story coherence. For the Memory Test, which was interleaved with the Viewing Phase in blocks, participants were cued to retrieve each video with a 3 second clip and then judged the vividness of their memory for the auditory content, visual content, and estimated the full video clip length.

1.2.3 Procedure

After giving informed consent, participants completed the viewing phase of the experiment (Figure 2). The 144 videos were divided into two lists of 72; each list contained 24 videos of each predefined valence category. Each participant viewed the videos from one of the two lists to limit the length of the experimental session, which lasted approximately 1 hour 30 minutes. Lists were assigned to participants in an alternating fashion. Therefore, 50 participants rated each of the 144 videos. The order of the videos was randomized per participant and the session was divided into 4 study-test blocks, each containing 18 videos, to allow for rest breaks. For

each study trial, participants first watched the video while adjusting a continuous slider to indicate how pleasant the video was to them at that moment in time on a scale of 'extremely unpleasant' (coded as 1) to 'extremely pleasant'' (coded as 9). This 'dynamic valence' slider started at a random position on the scale at the beginning of each trial, and participants were asked to adjust the slider as quickly as possible to reflect their impression of the video and to keep adjusting it as the perceived pleasantness changed. The location of the slider was sampled every 100ms. At the end of each video, participants were asked an additional 4 questions: overall valence ('summary valence') on a scale of 1 (extremely negative) to 9 (extremely positive), overall emotional intensity ('intensity') on a scale of 1 (not at all intense) to 9 (extremely intense), the familiarity of the video with the options of 'I have seen this exact news footage before', 'I am familiar with the news story but I have not seen this footage', and 'I have not seen or heard of this news story before', and finally if the story depicted in the video was coherent or 'easy to follow' with 'yes' or 'no' response options.

Immediately after watching all 18 videos in the study phase of a block, participants completed a memory test. On each test trial, participants were first shown the first 3 seconds of the video as a retrieval cue. After this clip, they were asked to rate how vividly they could recollect the auditory details about the video and the visual details of the video, both using the scales 1 (not at all vividly) to 9 (extremely vividly). Participants were instructed to try to remember as much of the video content as possible before responding. They were then shown a scale from 10 seconds to 60 seconds with tick marks at 10 second intervals and were asked to estimate the total duration of the video by moving the slider along the scale and pressing the spacebar to confirm their response. The slider appeared at a random location along this duration scale on every trial. All responses were self-paced.

1.3 ANALYSES & RESULTS

Videos were excluded prior to data analysis if more than 25% of participants rated the video as incoherent (16 videos). Two additional videos were removed from data analyses as a result of experimenter error: one because its duration was actually significantly longer than 52 seconds, and one because it showed almost identical news footage to a different video. The remaining sample of 126 videos (mean duration = 42.43 seconds, SD = 7.44 seconds) are included in all analyses below. All data for the videos can be found at http://www.thememolab.org/paper-videonorming, including the mean of all measures collected from participants - dynamic and summary ratings of emotional valence and emotional intensity, ratings of video familiarity, and mean memory vividness and duration estimates. All analyses were performed using R Version 3.5.0 with RStudio Version 1.1.456 (R Core Team, 2012). We used linear mixed effects analysis, with maximum likelihood estimation, from R's Ime4 package (Bates, Maechler & Bolker, 2012) to quantify the relationship between variables across videos and subjects. In all cases, random intercepts were included for subject and video, and random slopes were also included for subject. P-values for each fixed effect were obtained by likelihood ratio tests of the full model against a null model without the effect in question.

1.3.1 Summary Valence and Emotional Intensity Ratings

Summary valence and emotional intensity ratings collected at the end of each video were averaged across participants, and the distribution of these mean ratings can be seen in Figure 4a. We first analyzed the relationship between these ratings across the videos. Mean valence and mean emotional intensity displayed a stereotypical asymmetric v-shaped relation (for review see Kuppens et al., 2013). To quantify this relationship, we modeled emotional intensity as the dependent variable, with linear and quadratic valence terms as fixed effects. Valence was related to emotional intensity both linearly ($^{2}(1) = 124.52$, p < .001), $\beta = -1.22 \pm 0.08$ (standard

error) and quadratically ($^{2}(1) = 123.38$, p < .001), $\beta = 1.19 \pm 0.08$, such that videos on the more negative and positive ends of the valence spectrum were rated as more intense than neutral videos, but negative videos tended to be the most emotionally intense (Figure 3).

Next, we analyzed the variability of summary valence and emotional intensity across subjects. To this end, we iteratively correlated the vector of each participant's summary valence ratings for each video with the summary valence ratings of every other participant who had watched the same videos. The mean of these correlations (mean r = 0.74) reflects a high level of consistency of perceived valence across subjects. Repeating this process with emotional intensity ratings revealed that emotional intensity was also stable across subjects, (mean r = 0.40), although to a lesser degree than valence. To determine which videos were the most variable in their ratings across subjects, we calculated the standard deviation of summary valence (mean SD = 1.35) and emotional intensity (mean SD = 2.05) across subjects for each video. Notably, the standard deviation of the valence and emotional intensity measures did not vary according to their mean values, indicated by multiple regression analyses revealing no significant linear or quadratic relationship between mean summary valence and valence variability (*ps* > .125), or between mean summary emotional intensity and emotional intensity variability (*ps* > .145).

To explore the relationship between female and male ratings of summary valence and emotional intensity, we calculated the correlation across videos between mean female and mean male ratings. Summary valence ratings were highly correlated across sex, r(124) = 0.96, p < .001. emotional intensity ratings were also highly correlated between sexes, r(124) = 0.92, p< .001, suggesting that females and males rated the videos similarly.



Figure 3. Each video plotted by mean ratings of emotional intensity (1 = least intense, 9 = most intense) and valence (1 = most negative, 9 = most positive). Green line represents the linear relation between measures; purple line represents the quadratic relationship between measures.

1.3.2 Dynamic Pleasantness Ratings

We next investigated the properties of the dynamic valence ratings obtained for each video. In order to examine the time course of these ratings, the slider location data were downsampled to a rating every 500ms, and the mean rating across participants was calculated for each video at every time point (Figure 4b). To examine how much the valence of each video varied over time, we then calculated the standard deviation of those time point means for each video (Figure 4c). The first 5 seconds of dynamic valence ratings were excluded from all calculations since the valence slider appeared in a random location at the start of each video and participants took a few seconds to move the slider based on their first impression of the video content. Standard deviation of dynamic valence was strongly correlated with video emotional intensity ratings, r(124) = .56, p < .001, illustrating that negative and positive videos were associated with more

variability in continuous valence ratings over the video time course. Standard deviation of dynamic valence was not significantly correlated with summary valence (r < 0.20, p > .20).

To analyze the correspondence between dynamic valence ratings and summary valence ratings, we first correlated the mean of dynamic valence ratings with mean summary valence ratings for each video. This revealed a strong relationship, r(124) = 0.96, p < .001. To examine whether this correlation was driven by the beginning, middle, or end of each video, we again divided each video's mean dynamic time course into thirds, and correlated the mean dynamic valence of each third with the mean summary valence. The mean dynamic valence from the beginning third was strongly correlated with summary valence, r(124) = 0.89, p < .001. This relationship increased for mean dynamic valence within the middle third, r(124) = 0.95, p < .001, and the end third, r(124) = 0.99, p < .001, which had the highest correlation between dynamic and summary valence ratings. The peak of dynamic valence ratings was also calculated across subjects for each video by centering the valence scale about 0 and taking the maximum absolute value at any time point for each video. Similarly, peak dynamic valence was highly correlated with mean summary scalence ratings (r(124) = 0.97, p < .001).



Figure 4. Valence ratings. Each row represents data for a single video in order of (A) ascending mean summary valence. Participants rated summary valence on a scale from 1-9 (mean ratings ranged from 1.43 to 8.48). (B) Mean dynamic valence rating across subjects at each 500ms timepoint. Pink represents more negative ratings, turquoise represents more positive ratings. (C) Standard deviation of mean dynamic valence rating over time, representing how much valence was perceived to fluctuate within each video.

1.3.3 Memorability

Subjective memory vividness. We next addressed data from the memory test, which occurred immediately after video encoding. We first analyzed the relationship between visual and auditory memory vividness ratings and then tested the influence of summary valence and emotional intensity on subsequent memory vividness. Visual vividness and auditory vividness were highly correlated (r(124) = 0.96, p < .001) and so subsequent analyses use a single composite vividness measure calculated as the average of visual and auditory vividness, summary valence and emotional intensity, we tested a linear mixed effects model with vividness as the dependent variable and fixed effects representing linear and quadratic effects of summary valence (Figure 5a) and emotional intensity (Figure 5b). Summary valence influenced vividness linearly ($^2(1) = 21.85$, p < .001), $\beta = -0.33 \pm 0.07$, indicating that positive videos were remembered more vividly than more neutral or negative videos. The quadratic summary valence term was also significant ($^2(1) = 46.42$, p < .001), $\beta = 0.49 \pm 0.07$, meaning that highly negative or highly positive videos were remembered more vividly than more neutral or neutral videos. Neither the linear nor the quadratic emotional intensity terms uniquely contributed to the model fit.

As with summary valence and emotional intensity, we examined the stability of vividness by iteratively correlating each participant's vector of composite vividness ratings across videos with the composite vividness ratings of every other participant who had watched the same videos. The mean of these correlations revealed stability of video memorability across subjects (mean r = 0.35). Additionally, we again explored the relationship between female and male visual and auditory vividness ratings by calculating the correlation of mean female and mean male ratings across videos. Both visual vividness (r(124) = 0.90, p < .001) and auditory vividness (r(124) = 0.91, p < .001) were highly correlated between sexes.

Summary of Normative Ratings					
	valence	arousal	visual vividness	auditory vividness	
mean	5.03	3.92	6.94	6.34	
sd	2.03	1.36	1.20	1.21	
median	5.04	3.77	7.15	6.55	
min	1.43	1.49	3.00	2.53	
max	8.48	7.22	8.77	8.60	

Table 1. Summary statistics for emotion and memory ratings across videos.

Temporal memory precision. Our final set of analyses focused on memory for video duration. To examine overall accuracy for duration estimation, the mean correlation between actual and estimated duration was calculated within each participant. Pearson's correlation coefficients were averaged across participants after transformation to Fisher z values (mean z = 0.29, SE = 0.02). A one-sample t-test revealed that the true mean was significantly greater than zero, t(97) = 16.62, $\rho < .001$, meaning that participants were able to recall video durations with above-chance accuracy. We next asked whether temporal memory was influenced by vividness. To quantify memory precision for temporal duration, we calculated estimate error as (|*actual duration - duration estimate*]) / *actual duration* on a trial-by-trial basis. We then tested a linear mixed effects model with duration estimate error as the dependent variable and a fixed effect representing composite vividness. Vividness predicted duration error (²(1) = 26.11, $\rho < .001$), $\beta - 0.12 \pm 0.02$, indicating that the duration estimates of videos that were remembered vividly were most accurate (lower error). To test whether valence modulated memory for video duration, we next modeled duration error as the dependent variable with fixed effects for linear and quadratic effects of summary valence. Neither the linear or quadratic valence terms significantly

contributed to the model fit. Similarly, to test whether emotional intensity modulated memory for video duration, we again modeled duration error as the dependent variable with fixed effects for linear and quadratic effects of emotional intensity. Again, neither the linear or quadratic emotional intensity terms significantly contributed to the model fit, suggesting that temporal memory precision was not significantly affected by video valence or emotional intensity.



Figure 5. Each video plotted by mean ratings of (a) composite vividness (1= least vivid, 9 = most vivid) by valence (1 = most negative, 9 = most positive), and (b) composite vividness by emotional intensity (1 = least intense, 9 = most intense). Green lines represent the linear relation between measures; purple lines represent the quadratic relationship between measures.

1.4 SUMMARY & CONCLUSIONS

In this study, we developed a new stimulus set of real news broadcasts and collected ratings of emotionality and subjective memory for each video clip. The results of our norming study indicated that, as intended, the stimulus set varied in its emotional content and memorability, and that the emotional valence predicted the subjective vividness with which the videos were remembered. Summary valence ratings showed a pattern similar to that reported for other kinds of emotional stimulus sets (e.g., Marchewka et al., 2014): there was a linear relationship reflecting that videos that were more emotionally negative tended to be most emotionally intense, consistent with past work documenting a negativity bias for participant ratings of the valence and intensity of emotional stimuli (Kuppens et al., 2013). There was also a quadratic (Vshaped) relationship, reflecting that emotional intensity was greatest for the most negative and most positive videos, replicating many prior studies of these emotional components (e.g., Lang & Bradley, 2007). Overall, participants rated the videos as varying widely along the spectrum of valence, which makes them ideal for studies examining differential effects of positive and negative emotion. We also found that summary valence ratings were related to memory vividness both linearly and quadratically, replicating the common finding in memory literature that emotional memories are more subjectively vivid than their neutral counterparts (for review see LaBar & Cabeza, 2006). This pattern indicated that highly emotional videos were remembered more vividly than neutral videos, and memory vividness was particularly high for positive videos. Laboratory experiments using words or static images typically find memory enhancements for negative items (for review see Kensinger, 2007), but enhancements in memory for positive materials tend to be more variable (for review see Bennion et al., 2013), although they are often seen for autobiographical events (D'Argembeau et al., 2003). The current stimulus set may be particularly useful, then, for investigating the effects of valence on memory, as well as for relating studies of laboratory-based and autobiographical memories. As such, it can facilitate examination of the neural and cognitive processes underlying dynamic, complex emotional experiences. Thus, I will use this database in the following studies to investigate the modulation of emotional memories.

2.0 DIFFERENTIAL EFFECTS OF REAPPRAISAL AND SUPPRESSION-BASED REGULATION STRATEGIES ON MEMORY FOR NATURALISTIC EMOTIONAL EVENTS

Rosalie Samide, Elizabeth Kensinger, and Maureen Ritchey

2.1 OVERVIEW

As discussed previously, numerous emotion regulation strategies may be used to regulate negative memories, including *memory reappraisal* and *memory suppression*. While reappraisal may reduce negative affect elicited by an ongoing (Gross 1998; Richards and Gross 2000) or past unpleasant experience (e.g., Holland and Kensinger 2013a; Holland and Kensinger 2013b; Kross et al. 2009), little is known about the lasting effects of memory reappraisal on memory guality. Likewise, while memory suppression studies using 'think/no-think' paradigms (Anderson and Green 2001 have found that suppression can reduce recall of neutral stimuli (Detre et al. 2013; Anderson et al. 2004), emotional stimuli have yielded mixed results. While some research has found that suppressing memories for aversive words (Depue et al. 2006; van Schie et al. 2013) or images (Depue et al. 2007; Küpper et al. 2014) reduces recall compared to a baseline condition in which stimuli were neither retrieved nor suppressed, other work has failed to find any effect of suppression on recall for emotional stimuli (Nørby et al. 2010). Furthermore, studies using think/no-think paradigms have only rarely assessed the effects of suppression on later perceived valence (see Stephens et al. 2013). Thus, more research is necessary to establish the long-term effects of memory suppression on both emotional memory recall and valence. Considering the impact of memory reappraisal and memory suppression on the longterm accessibility of emotional memories is particularly important given that a consequence of emotion is to flag features of our environment that are relevant to survival (for review see Barnett 2019) and facilitate learning from negative experiences. Therefore, while forgetting a negative memory might feel ideal, in reality, it may be maximally adaptive to reduce the memory emotionality to the extent that it does not cause excessive distress, while preserving relevant information. We hypothesize that memory reappraisal may be better suited to achieving these goals relative to memory suppression, which impairs later recall (e.g., Depue et al. 2006; Depue et al. 2007).

The current study directly compared the effects of memory reappraisal and memory suppression on later memory emotionality and accessibility. To do so, we employed videos of real events (Samide et al. 2019; see 1.0) to increase ecological validity while maintaining experimental control. Participants encoded naturalistic emotional events and then engaged in multiple rounds of emotion regulation on their memories for each event. For each memory, participants were instructed to either reappraise or suppress their memory for the event, compared to retrieval-only and no-retrieval baseline conditions. After a 24-hour delay, participants attempted to recall each event and memory emotionality, accuracy, and details were assessed. We hypothesized that memory reappraisal would reduce the negative emotionality of memories compared to suppression and retrieval-only, whereas suppression would have no effect on memory emotionality compared to no-retrieval. We further predicted that memory reappraisal would preserve memory accessibility and quality compared to retrieval-only and no-retrieval-only and no-retrieval-only and no-retrieval-only and retrieval-only, whereas suppression would have no effect on memory emotionality compared to no-retrieval. We further predicted that memory reappraisal would preserve memory accessibility and quality compared to retrieval-only and suppression, whereas suppression would reduce memory accessibility and quality compared to reappraisal and no-retrieval.

2.2 METHODS

2.2.1 Participants

Participants (n = 61, 34 female) with a mean age of 19.22 years were recruited from the Boston College Sona System. All participants were required to be 18-35 years old, have learned English before age 6, have normal or normal-to-corrected vision, no history of neurological or psychological disorder, and no history of psychoactive medication. Participants were excluded before data collection (2 participants) if they reported being 'moderately' or 'highly' distressed or upset before the beginning of the experiment session based on the Positive and Negative Affective Schedule (PANAS; see below) to minimize pre-experiment differences in negative affect and protect against unnecessary emotional burden on participants. Fourteen participants were excluded from analyses for the following reasons: failure to report any descriptive details at cued recall (1 participant); computer or experimenter errors (e.g., video playback issues) leading to interrupted or incomplete data collection (10 participants); failure to return for the second session (1 participant); insufficient numbers of trials per condition (1 participant; see criteria details below). Thus, 48 participants were considered for data analysis.

2.2.2 Stimuli

Stimuli were 40 emotionally negative, 10 positive, and 10 neutral video clips taken from a normed database of real news broadcasts described in Samide et al. 2019. Valence categories were determined from normative valence ratings (Table 1) made on a scale of 1 ('most negative') to 9 ('most positive') included in the stimulus database. The subset of videos in the current study were additionally selected based on the experimental goals of having thematically distinct content and the ability to create reasonable reappraisals.

Normative Valence Ratings					
valence category	mean	min	max		
neg	2.86	1.63	4.29		
neu	5.96	5.62	6.19		
pos	8.01	7.85	8.48		

Table 1. Normative valence ratings of video stimuli (Samide et al. 2019) selected for the current study.

The short video clips, which ranged from 20-52 seconds in duration (mean = 42 s) included a variety of topics typically seen during news reports (e.g., soldier homecomings, car accidents, economy briefings). Importantly, these stimuli are dynamic, multimodal, and depict real-life events, thus allowing for experimental control while also improving the ecological validity of the research. Because our goal was to examine the effects of emotion regulation strategies on memories for real-world events, it was not possible to perfectly match the stimuli on their perceptual and semantic attributes. However, stimuli were randomized across regulation conditions and only negative videos were considered in the primary analyses, thus mitigating concerns that differences across conditions could be driven by differences in content. For each negative video, brief descriptions of the central negative event were generated (e.g., 'man injured'). Experimenters also generated an additional brief phrase for each negative video to aid participants in reappraising (e.g., 'but recovered fully'). These reappraisal hints either contained positive information included in the video clip (i.e., a 'silver lining') or plausible positive outcomes not shown in the clip (e.g., 'awareness raised'). Over the course of data collection, it became clear that for some videos, the reappraisal hints were perceived as uncomfortable or insensitive due to their focus on possible positive outcomes of an extremely negative event. Therefore, we ran a post hoc norming study in which a separate group of 12 participants drawn from the same

population watched the negative videos and rated the experimenter-generated reappraisals on a 5-point scale of 'very uncomfortable' to 'very comfortable.' Four videos with reappraisal hints were rated as 'very uncomfortable' by more than 50% of participants; these videos were then excluded from all analyses.



Figure 1. Schematic representation of the experimental paradigm. Participants encoded 40 videos and rated the emotionality of each. They then engaged in reappraisal, suppression, retrieval-only, or no-retrieval to regulate their memories. The next day, participants completed cued recall for each video and again rated the emotionality and vividness.

2.2.3 Materials

To assess mood, participants completed the PANAS (Watson et al. 1988) before and after each experimental session. After Cued Recall, participants additionally completed the State-Trait Anxiety Inventory (STAI; Spielberger et al. 1970), Beck Depression Inventory (BDI; Beck et al. 1961), and Emotion Regulation Questionnaire (ERQ; (Gross and John 2003).

2.2.4 Procedure

The experiment (Figure 1) took place across two sessions 24 hours apart. On Day 1, participants completed informed consent, *Encoding*, and *Emotion Regulation* immediately following. After a 24-hour delay, participants returned to the lab to complete *Cued Recall*. Instructions for each phase were administered directly before the beginning of the phase (e.g., Emotion Regulation instructions were administered before the Emotion Regulation phase and after Encoding).

Encoding. Participants were instructed to carefully watch 60 videos of real news broadcasts distributed across 4 blocks. After each video, participants rated the valence of the video on a scale of 1-6 ("very negative" to "very positive") and emotional intensity of the video on a scale of 1-6 ("not at all intense" to "very intense"). Positive and neutral videos were included to prevent negative mood induction and habituation to negative stimuli, as well as to encourage use of the entire rating scale, and were not included in analyses of interest.

Emotion Regulation. Participants were then cued to remember some of the negative videos and, as they brought the content to mind, asked to apply different emotion regulation strategies to their memories. Negative videos were divided into 4 lists of 10 videos randomly for each participant, corresponding to the 4 memory strategy conditions: reappraise, suppress, retrieve-only, and no-retrieval. Positive and neutral videos were not included in this phase. For each Emotion Regulation trial, the first 3 seconds of the video were played as a memory cue while a very short description of the video was presented at the top of the screen. During the cue, participants were instructed to begin remembering which video corresponded to the 3-second clip. Each video cue was surrounded by a colored border indicating which strategy participants should prepare to employ (green = retrieve-only, blue = reappraise, red = suppress). After the 3-

second cue, the video disappeared but the border indicating strategy remained on the screen for an additional 6 seconds, during which participants engaged in the assigned emotion regulation or retrieval strategy. The experimenters confirmed verbally that participants understood the color-to-strategy mapping, but the instructed strategy for each trial was also clear from additional information presented on-screen. For retrieval-only trials, the description remained on the screen and participants were instructed to continue remembering the video naturally in as much detail as possible. For reappraise trials, the description was accompanied by an additional brief reappraisal hint (see Stimuli and Figure 1 for example). Participants were instructed to use the reappraisal hint in order to reframe the video to render it less emotionally negative. For suppress trials, the description was removed from the screen after the cue and participants were instructed to stop thinking about the video, keeping their mind completely blank. Additionally, some videos were not cued during Emotion Regulation (no-retrieval condition) to provide a baseline control condition. After each emotion regulation trial, participants rated their success at employing the indicated strategy on a 1-6 scale ("not at all successful" to "very successful"). This rating allowed for later trial exclusion on the basis of unsuccessful retrieval or regulation. Regulation strategies were blocked such that all the trials for any one strategy were completed before moving onto another strategy, in order to reduce the cognitive demand of repeatedly switching between strategies. Participants completed three rounds of Emotion Regulation (i.e., each video was regulated using the same strategy three times) since there is evidence that multiple regulation attempts are more effective than one (Denny et al. 2015). For each participant, the order of the videos within each strategy and the order of the strategies was randomized for each round.

Cued Recall. Each video presented during Encoding was cued with the first 3 seconds of the clip, and participants were instructed to remember the full video and take as much time as they need to type a description in as much detail as possible, including (but not limited to) information

about the storyline, temporal and spatial setting, visual and auditory details, and any thoughts, feelings, or reactions that they had in response to the video. Immediately after each description was completed, participants rated the valence and emotional intensity of their memory for the clip using the same scales shown at encoding, and the vividness of their memory on a scale of 1-6 ("very hazy" to "very vivid"). If they could not remember anything about the video, participants were instructed to leave the description blank and use a 'forgot' option on the valence, intensity, and vividness scales.

2.2.5 Analysis

All primary analyses were conducted using only successfully regulated items (see 'Emotion regulation success'). Some analyses also required that items be remembered (e.g., to assess the effect of strategy on emotionality at recall). For those analyses, an additional 7 participants were excluded for having near-floor recall performance (fewer than two successfully regulated and remembered stimuli in each condition of interest), leaving a subsample of N = 40.

All analyses were conducted using R version 3.5.0. For all ANOVAs, Mauchly's Test was used to assess sphericity. For effects for which the sphericity assumption was violated, reported degrees of freedom and *p*-values were corrected using Greenhouse-Geisser estimates of sphericity. To limit the number of comparisons, when a main effect of memory strategy was identified, planned pairwise comparisons included t-tests to evaluate potential differences between three pairs: the reappraisal and retrieval-only conditions, reappraisal and suppression conditions, and suppression and no-retrieval conditions. The three comparisons were evaluated with a Bonferroni corrected alpha = 0.0167.

Affective measures at encoding. To confirm that our a priori emotion conditions were distinguishable by participants' own subjective ratings, mean valence and mean intensity ratings were calculated within the predetermined valence categories (negative, positive, neutral). Mean
valence ratings and mean intensity ratings were entered into separate ANOVAs with valence category as a factor. To confirm that valence categories were sufficiently distinct from one another, three paired t-tests were conducted to test for differences in valence and intensity ratings between the positive, negative, and neutral valence categories.

Emotion regulation success. To evaluate the success with which each emotion regulation (or retrieval) strategy was employed, regulation success rates were determined by calculating the percentage of videos that were regulated (or retrieved) with at least a 3/6 success rating for at least 2/3 rounds. An ANOVA was used to test for a main effect of strategy on regulation success. Videos that were not regulated successfully were excluded from further analysis. Participants with fewer than 2 trials remaining in any of the conditions of interest were excluded from analysis. Trial numbers for each of the conditions of interest are reported in Table 2. Based on these criteria, we retained 48 participants for analyses considering all successfully regulated trials and 40 participants for analyses considering only successfully regulated and remembered trials.

Number of Trials							
	re	gulated		regulated & remembered			
strategy	mean	min	max	mean	min	max	
no-retrieval	8.98	6	10	4.95	2	9	
reappraise	7.08	3	10	5.72	2	10	
retrieval-only	7.50	3	10	6.10	2	10	
suppress	7.21	2	10	4.83	2	10	

Table 2. Number of trials per condition (out of 10 possible) included in analyses that required items to be successfully regulated (N = 48) and successfully regulated and remembered (N = 40). Note that noretrieval trials were automatically counted as successfully regulated, and thus the only missing not-retrieved items were from a single participant whose encoding phase ended prematurely.

We also assessed whether participants' subjective sense of regulation (or retrieval) success was related to their habitual use of reappraisal, as quantified by reappraisal scores on the ERQ (see Gross and John 2003 for information on scoring). Mean regulation success ratings were calculated within strategy (reappraise, suppress, retrieval-only) and three Pearson's correlations were conducted to test for significant relationships between ERQ reappraisal scores and mean regulation success ratings for each condition.

Affective measures at cued recall. We first examined the effects of memory strategy on separate valence and intensity ratings. To examine how memory strategy was related to valence at cued recall, mean recall valence ratings were calculated within memory strategy for each participant. A one-way repeated-measures ANOVA was run with strategy as a factor and recall valence rating as the dependent variable. Mean recall emotional intensity was evaluated similarly. To account for item-specific variability in valence ratings observed before and after emotion regulation, the change in valence for each item was calculated as *recall valence rating - encoding valence rating*. Mean valence change was then calculated for each strategy within participants, and an ANOVA was run with strategy as a factor and valence change as the dependent variable. Change in emotional intensity from encoding to recall was calculated and analyzed using the same method. In order to be included in these analyses on affective measures at cued recall, videos must have been successfully remembered, as defined below. Therefore, these analyses were conducted using the subsample of 40 participants with sufficient remembered trials. If a main effect of strategy on valence or intensity measures was found, planned comparisons were assessed as described above.

Memorability ratings. To examine how memory strategy affected the accessibility of memories, we first assessed how many videos were remembered within each regulation condition. Videos were considered to be 'remembered' if the 'forgot' option was not selected for the vividness, valence, and intensity ratings during cued recall. We additionally required that at

least one detail was reported for remembered videos in order to ensure that the item was actually recalled rather than the cue word being simply recognized. The percent of videos remembered / total videos, was calculated within strategy for each of the 48 participants. A one-way repeated-measures ANOVA with strategy as a factor and percent videos remembered as the dependent variable was used to test for effects of strategy on the number of videos remembered. To test whether strategy modulated memory vividness, we calculated the mean vividness rating of remembered videos within regulation conditions and ran an ANOVA with dependent variable mean vividness rating and factor memory strategy. Strategy effects on vividness were thus assessed using the 41-participant subsample in order to enable the exclusion of forgotten items, which could not be assessed for vividness. If a main effect of strategy on these memory measures was found, planned comparisons were assessed.

Cued recall data. Next, to assess the effects of memory strategy on memory detail, we quantified the number of details in each Cued Recall description using a scheme based on Levine et al. 2002 for videos that were successfully regulated. Recall responses were coded by a rater blind to experimental condition. A 'detail' was considered any phrase containing unique information about the video or the participants' thoughts or mental state as it related to the video. The details in each description were quantified into the following categories: event (e.g., "a man was in an accident"), time (e.g., "at night"), place (e.g., "in Florida"), emotion (e.g., "she was upset"), reaction (e.g., "it made me sad"), visual (e.g., "his hair was blond"), extra (i.e., information that did not fit into the aforementioned categories), and repeated details (i.e., redundant information). Initially dividing the details into discrete categories allowed for the possibility of analyzing differential strategy effects on types of details; however, we found that the vast majority of details were event-related, and thus evaluating details in separate categories was not possible. Thus, the total number of details remembered was calculated by adding the number of details within each category and subtracting the number of repeated

details, if any. Total number of details was then averaged within regulation condition, and the effect of emotion regulation was tested using a one-way repeated-measures ANOVA with dependent variable mean number of details and factor memory strategy. To assess the effect of memory strategy on memory accuracy, remembered details for videos that were successfully regulated were additionally coded for accuracy by comparing each detail to the video. Reappraisal hints (i.e., silver linings or plausible positive outcomes) were treated as event details and thus similarly coded for accuracy if reported. Reaction details were not considered for accuracy because of their subjective nature. Both remembered and forgotten trials from all 48 participants were included. To assess inter-rater reliability, a second experimenter blind to experimental condition coded the recall data and the correlation of the number of details counted by the raters was calculated for total number of details (r = 0.94), correct details (r = 1.94), correct details 0.91), and event details, r = 0.91. To evaluate whether memory strategy affected the proportion of correct details remembered, we calculated an accuracy measure as correct details recalled / total recalled for each video (excluding reaction details), which was then similarly averaged within strategy and assessed in an ANOVA with strategy as a factor. This analysis was restricted to remembered items, and was thus conducted using the 40-participant subsample. If a main effect of strategy on these memory measures was found, planned comparisons were assessed.

2.3 RESULTS

Affective measures at encoding. In order to confirm that participants perceived the videos in the negative, positive, and neutral valence categories as such, we first assessed whether valence and intensity ratings at encoding differed by valence category. As expected, there was a significant effect of valence category on valence ratings at encoding, F(2.84, 133.47) =

629.88, Greenhouse-Geisser (GG) corrected p < .001, $\eta^2_g = 0.91$. Post hoc tests revealed that participants rated videos in the positive category (mean = 5.36, SD = 0.50) as significantly more positive than videos in the negative category (mean = 2.13, SD = 0.38, t(47) = -28.70, p < .001) or neutral categories (mean = 4.41, SD = 0.43, t(47) = -16.60, p < .001), and videos in the negative category were rated as significantly more negative than videos in the neutral category, t(47) = -22.45, p < .001. There was also a significant effect of valence category on intensity at encoding, F(2,94) = 117.69, p < .001, $\eta^2_g = 0.45$. Negative videos (mean = 3.63, SD = 0.78) were rated as significantly more intense than neutral videos (mean = 1.75, SD = 0.68, t(47 = 17.52, p < .001) and positive videos, mean = 2.86, SD = 1.07, t(47) = 5.54, p < .001. Positive videos were also rated as significantly more intense than neutral videos, t(47) = 9.12, p < .001. Therefore, we concluded that the stimuli included in the experiment elicited the intended affective responses. The rest of the analyses included only negative stimuli.

Emotion regulation success. To confirm that effects of memory strategy on affective or memory measures were not due to systematic differences in regulation success, we next calculated the percent of negative stimuli that were successfully regulated (success rate) within each strategy for the main 48-participant sample. A one-way ANOVA revealed no effects of strategy on success rate (F(2,94) = 0.52, p = 0.70), meaning that participants reported similar levels of success in implementing the reappraisal, suppression, and retrieval-only strategies. Across the three strategies, the mean success rate was 81.5%, SD = 0.19, demonstrating that participants were generally able to employ the strategies as instructed. The following analyses were limited to successfully regulated trials.

Additionally, to assess whether regulation (or retrieval) success was related to habitual use of reappraisal, we used Pearson's correlations to test for a relationship between ERQ habitual reappraisal scores and mean success ratings within strategy. Habitual reappraisal scores (mean = 5.71, SD = 0.93) were not significantly related to mean regulation success for reappraisal

(mean = 4.03, SD = 0.81, t(41) = -0.47, p = 0.64), suppression (mean = 4.06, SD = 0.78, t(41) = -1.35, p = 0.17), or retrieval-only (mean = 4.49, SD = 0.71, t(41) = -0.29, p = 0.77), indicating that the extent to which participants reappraise in everyday life had no effect on their ability to regulate or retrieve memories during the experiment.

Affective measures at recall. To test our main hypothesis that reappraisal and suppression have differential effects on memory emotionality, we evaluated the effects of strategy on recall valence and intensity. We first considered valence (Figure 2a). As predicted, there was a main effect of strategy on mean valence ratings at cued recall, F(3,117) = 3.43, p = .02, $\eta^2_g = 0.04$. Reappraised memories (mean = 2.52, SD = 0.58) were rated as less negative than memories that were only retrieved (mean = 2.26, SD = 0.47, t(39) = 2.44, p = .019), though this comparison did not survive correction for multiple comparisons. Reappraised memories were rated as significantly less negative than memories that were suppressed (mean = 2.23, SD = 0.63, t(39) = 2.74, p = 0.009), meaning that memory reappraisal is also more effective at reducing negative valence than suppressing an unpleasant memory. There was no difference in mean valence between memories in the suppression and no-retrieval (mean = 2.35, SD = 0.46) conditions, t(39) = 0.02, p = 0.23), meaning that suppression did not reduce negative valence more so than merely not retrieving an event.

We also investigated whether this pattern was observed when accounting for item-level variability by examining the change in valence from recall to encoding for each video (Figure 2b). There was a main effect of memory strategy on change in valence (F(3,117) = 3.05, p = .031, $\eta^2_g = 0.05$) such that reappraised memories (mean change = 0.33, SD = 0.50) became significantly more positive after emotion regulation than retrieved-only memories (mean change = -0.0006, SD = 0.50), t(39) = 2.99, p = .005. Thus, memory reappraisal reduced the negative valence associated with individual events more so than just remembering an event. There was



Figure 2. Effects of memory strategy on later emotionality. Reappraisal was associated with reduced negative valence at recall on average compared to suppression (a), and a greater reduction in negative valence at an item level compared to retrieval-only (b). There were no differences in mean recall intensity (c) but suppression was associated with less reduction in intensity than no-retrieval (d). Shaded rectangles and error bars represent standard error of the mean. NO-RET = no-retrieval, SUPP = suppression, REAPP = reappraisal, RET-ONLY = retrieval-only. ** = p < .01. *** = p < .001.

no difference in change in valence between memories in the suppression (mean change = 0.12, SD = 0.69) and no-retrieval conditions (mean change = 0.18, SD = 0.46, t(39) = -0.53, p = 0.60), indicating that suppression did not reduce the negative valence of individual events above and beyond not retrieving the memory for an event. We also did not observe a difference in significant change in valence between memories in the reappraisal and suppression conditions, t(39) = 1.82, p = .06. In summary, memory reappraisal reduced negative affect compared to

simply retrieving an event, whereas suppression had no effect on negative affect relative to not retrieving the event memory.

We additionally examined the effects of memory strategy on the emotional intensity experienced by participants when recalling the videos. There was no effect of strategy on mean intensity at recall (Figure 2c), F(3,117) = 0.89, p = 0.45. However, there was a main effect of strategy on item-specific changes in intensity (Figure 2d), F(3,117) = 3.71, p = .014, $\eta^2_g = 0.03$. Memories that were suppressed (mean change = -0.50, SD = 0.74) were associated with a significantly smaller reduction in intensity compared to memories that were not retrieved, mean change = -0.84, SD = 0.75, t(39) = -2.64, p = 0.012. This effect appears to be at least partially driven by the fact that remembered videos in the no-retrieval condition tended to be higher in intensity at encoding but not at recall. However, this finding may also indicate that suppression is less effective at reducing the emotional intensity of an event relative to not retrieving the event memory. We did not observe a difference in change in intensity between reappraised memories (mean change = -0.52, SD = 0.89) and retrieved-only (mean change = -0.70, SD = 0.76) (t(39) = 1.28, p = 0.21), or between reappraised and suppressed memories, t(39) = -0.20, p = 0.84. Thus, while memory reappraisal did not have a significant effect on the emotional intensity of event memories, suppression reduced emotional intensity even less than not engaging in any emotion regulation or recall.

Memory measures. We next evaluated whether reappraisal and suppression differentially affected memory recall. We first tested for effects on memory accessibility, here defined as the percent of videos recalled with at least 1 detail and not reported as 'forgotten' on the recall valence, intensity, or vividness scales (Figure 3a). There was a main effect of strategy on the percent of videos remembered, F(3.81, 179.26) = 32.21, GG-corrected p < .001, $\eta^2_g = 0.30$. Videos that were reappraised (mean = 0.79, SD = .17) were remembered more frequently than videos that were suppressed, mean = 0.55, SD = .27, t(47) = 6.17, p < .001. There was no

difference in percent remembered between videos that were reappraised and retrieved-only (mean = 0.81, SD = 0.15, t(47) = -0.49, p = 0.64) or between videos that were suppressed and not-retrieved, mean = 0.55, SD = 0.16, t(47) = -0.05, p = 0.96. These results suggest that memory reappraisal maintained memory accessibility compared to simply retrieving a memory, whereas suppression reduced memory accessibility compared to reappraisal but at a similar level to if the event memory was never retrieved.

In order to better understand how memory strategy might differentially modulate memory guality, we then tested the effects of strategy on the number of total details recalled, including details that were scored as both accurate and inaccurate (Figure 3c). There was a main effect of strategy on number of details (F(3,141) = 27.45, p < .001, $\eta^2_g = 0.19$) such that reappraised memories (mean = 3.51, SD = 1.59) were remembered with significantly more details than suppressed memories, mean = 2.37, SD = 1.49, t(47) = 5.32, p < .001. There was no difference in number of remembered details between videos that were reappraised and videos that were retrieved-only (mean = 3.78, SD = 1.34, t(47) = -1.34, p = 0.19) or between videos that were suppressed and not-retrieved, mean = 2.30, SD = 1.01, t(47) = 0.33, p = 0.74. There was also a main effect of strategy on subjective memory vividness of remembered videos (Figure 3b), F(3, 117) = 6.06, p < .001, $\eta^2_g = 0.07$. Retrieved-only memories were marginally more vivid than reappraised memories, but this comparison did not survive corrections for multiple comparisons, t(39) = 2.22, p = .03. Other planned comparisons also did not yield significant results, ps > .38. Converging with our memory accessibility results, these findings suggest that memory reappraisal maintained memory detail compared to retrieval-only, whereas suppression reduced memory detail compared to memory reappraisal, similarly to if the memory was not retrieved. However, once a memory was retrieved, vividness was not significantly affected by strategy.



Figure 3. Effects of strategy on later memory. (a) Reappraised memories were recalled with comparable frequency compared to retrieved-only memories, but significantly more frequently than suppressed memories. (b) Reappraised and suppressed memories were similarly vivid. (c) Reappraised memories were also remembered with comparable numbers of total details as retrieved-only memories, whereas suppressed memories and not-retrieved memories were remembered with similar and lower levels of detail. Solid bars = correct details. Transparent bars = incorrect details. Error bars = standard error of the mean. NO-RET = no-retrieval, SUPP = suppression, REAPP = reappraisal, RET-ONLY = retrieval-only. *** = p < .001.

Finally, because the strategies could differentially modulate the number of details remembered, the quality of those details, or both, we calculated the proportion of correct details to total details remembered in videos that were remembered and successfully regulated to examine the possibility that incorrect details were introduced into the memories. Across conditions, most recalled details were accurate (Figure 3C), and there was no effect of strategy on detail accuracy, F(3, 117) = 2.53, p = .06, suggesting that the strategies did not significantly affect the number of inaccurate details recalled.

2.4 SUMMARY & CONCLUSIONS

Using naturalistic, multimodal stimuli, the current study found that reappraisal reduced negative emotionality while preserving the accessibility and detail of memories. In contrast, suppression had no effect on memory emotionality but was associated with reduced memory accessibility and detail compared to reappraisal. Our findings are consistent with research showing that retrieval practice enhances memory retention (Nungester and Duchastel 1982; Roediger and Karpicke 2006) and build upon numerous studies that have found reappraisal during ongoing events to be considerably more effective at reducing negative affect than *expressive suppression*, the deliberate concealment of outward emotional expression (Richards and Gross 2000; Ochsner et al. 2002; Gross and John 2003; Dillon et al. 2007; Hayes et al. 2006). Together, our findings suggest that memory reappraisal might be an ideal emotion regulation strategy in that it reduces the emotionality associated with aversive memories while maintaining memory for potentially relevant details.

One notable difference between memory reappraisal and memory suppression is the degree of memory reactivation that occurs during the employment of these strategies. While memory suppression deliberately avoids strong memory reactivation, memory reappraisal requires strong reactivation in order for event details to be evaluated and appraised. Our results are consistent with a growing body of research using fear conditioning (Nadel et al. 2012; Hupbach et al. 2013) and episodic memories (for review see Samide and Ritchey 2020) demonstrating that reactivation is critical for memory modification. While there are considerable challenges to directly applying these techniques to modifying complex autobiographical memories (Phelps and Hofmann 2019), here, we demonstrate that engaging memory reactivation through memory reappraisal can change the emotionality of a memory. In turn, our results support the idea that

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reactivation plays a critical role in modifying naturalistic emotional episodic memories (Samide and Ritchey 2020).

3.0 NEURAL CORRELATES OF REAPPRAISING NATURALISTIC EMOTIONAL MEMORIES

Rosalie Samide, Rose Cooper, Elizabeth Kensinger, & Maureen Ritchey

3.1 OVERVIEW

As demonstrated, memory reappraisal can reduce the negative valence of naturalistic episodic memories while maintaining memory accessibility. Because memory valence seems to remain modified 24 hours after memory reappraisal occurred, these findings suggest that memory updating is occurring. However, little is known about the neural mechanisms supporting reappraisal as a memory updating strategy.

Prior work on reappraisal, which has largely focused on reappraising ongoing events, has shown that using reappraisal to downregulate negative emotion is associated with activation of prefrontal control regions (see Buhle et al. 2014 for meta-analysis). Studies specifically examining the reappraisal of autobiographical memories found that reappraisal during recall was associated with prefrontal activation within vmPFC, dIPFC, and vIPFC (Kross et al. 2009; Holland and Kensinger 2013), regions that are thought to be involved in fear extinction (Kalisch et al. 2006; Phelps et al. 2004; Delgado et al. 2008), maintaining reappraisal in working memory (Curtis and D'Esposito 2003; Dillon and Pizzagalli 2013; Wager and Smith 2003), and reappraisal selection (Simmonds et al. 2008; Buhle et al. 2014), respectively. Interestingly, one study on autobiographical memory reappraisal also found a lasting behavioral effect of reappraisal, such that, on a post-scan test, memories that had been reappraised in the scanner were rated as less negative than memories for which participants maintained negative emotion

(Holland and Kensinger 2013). However, it is unknown how neural processes during memory reappraisal relate to this finding, or to longer-lasting changes in memory valence.

Though the mechanism underlying this hypothesized memory modification is unknown, reconsolidation literature suggests that reactivation prior to modification attempts may be key to successful memory updating (for review see Samide and Ritchey 2020). For example, reactivating a fear memory prior to extinction prevents fear reinstatement (Agren et al. 2012; Kindt et al. 2009; Schiller et al. 2010), and reactivating an episodic memory, then disrupting reconsolidation, causes memory deficits (Kroes et al. 2014). Thus, reactivating an unpleasant memory prior to reappraisal may render the memory representation labile, resulting in a lasting change to the memory valence.

To quantify memory reactivation, representational similarity analysis (RSA; Kriegeskorte et al. 2008) has commonly been used to compare multivariate patterns of activation (Haxby et al. 2001) for a particular feature or item between encoding and retrieval phases. Prior work has found that static images, like objects (Favila et al. 2018) or scenes (Wing et al. 2015; Ritchey et al. 2013), and multimodal, dynamic stimuli, like movies (Chen et al. 2017), are reinstated during recall in occipitotemporal cortex (OTC). Furthermore, it has been shown that emotion enhances encoding-retrieval pattern similarity within mid-occipital regions (Ritchey et al. 2013) and ventral occipital temporal cortex (Kark and Kensinger 2015). Thus, measuring reinstatement within occipitotemporal cortex allows us to quantify the relationship between the extent of memory reactivation and a lasting reappraisal-mediated reduction in negative memory valence.

Using the news video database with fMRI, I directly tested the hypothesis that neural markers of memory reactivation occurring before attempts to regulate facilitates a reduction in the negative affect of unpleasant naturalistic memories. In a two-day paradigm, subjects watched emotionally negative, neutral, and positive videos from the previously described stimulus database and

rated the valence and emotional intensity of each clip. Then, in the fMRI scanner, subjects were cued to recall each video, then asked to either continue remembering (retrieval-only) or reframe (reappraise) the memory to make it less emotionally negative. On the following day, subjects were again cued to recall each video, type a detailed description of their memory, and rate memory vividness, valence, and intensity.

Using both univariate and multivariate analysis techniques, I examined the relationship between recall-related brain activity and behavioral measures of memory affect. First, characterized which brain regions are sensitive to the valence and success of event retrieval and identify activity related to memory reappraisal. Then, I assessed whether *univariate activity* within memory-related regions during memory reappraisal is positively related to a reduction in negative valence. I then used *pattern similarity analysis* to directly test the hypothesis that the degree of memory reactivation prior to memory reappraisal is positively related to a reduction in valence.

3.2 METHODS

3.2.1 Participants

Subjects (N = 35, 20 female, 15 male) were recruited from Boston University, Boston College, and the surrounding community using online job postings and flyers. Participants were fluent English speakers (learned English by age 6) between the ages of 18-35 (mean age = 22.29 years) and had no history of psychiatric or neurological disorders or use of psychoactive medications. To maximize the correspondence of basic brain architecture across participants, they were required to be right-handed. Subjects completed MRI safety screening and COVID screening in accordance with the Boston University Cognitive Neuroimaging Center. Five subjects were excluded for the following reasons: missing Day 2 behavioral data due to a computer problem (1), excessive motion (2), and exiting the scanner early due to discomfort (2). Therefore, a final sample of N = 30 (16 female) will be included in the following analyses.

3.2.2 Materials

Stimuli were composed of 48 video clips varying in valence (24 negative, 12 neutral, 12 positive) taken from real news broadcasts (see **1.0**; Samide et al. 2019). Each video clip was paired with a unique, neutral cue word that was semantically related to the video content (e.g., *market* paired with a report about a dog meat market in china; *website* paired with a report about the creation of a female-focused career networking website). The semantic similarity of words within each valence category (negative, neutral, and positive) and between each valence category was calculated using the R function LSAfun (Günther et al. 2015) with EN_100k semantic space to help ensure that any differences in behavioral or neural measures between valence categories would not be driven by cue word similarity. On a scale of 0.0 to 1.0 where 1.0 represents the perfect similarity score of a word with itself, average similarity score between and within valence categories ranged from 0.251 to 0.317 (see Table 4), suggesting that the semantic relatedness of the cue words was similar within and across valence categories.

Cue Word Similarity							
valence category comparisonsemantic similarity score (0.0-1.0)							
negative-negative	0.289						
neutral-neutral	0.316						
positive-positive	0.317						
negative-neutral	0.256						
neutral-positive	0.251						
negative-positive	0.268						

Table 1. Semantic relatedness scores.

Because the video stimuli used in this study vary in valence, and the manipulation aims to modulate individuals' affective responses to those stimuli, participants completed a pre-study Positive and Negative Affect Schedule (PANAS; Watson et al. 1988) immediately before each experimental session to verify that they were not currently experiencing severe emotional distress or upset. At the end of the experiment, participants also completed the State-Trait Anxiety Inventory (STAI; Spielberger et al. 1970) to assess current and tonic anxiety levels, the Beck Depression Inventory (BDI; Beck et al. 1961), the Emotion Regulation Questionnaire (ERQ; Gross and John 2012), and a short debriefing questionnaire.

3.2.3 Procedure

This experiment paradigm (Figure 1) follows a design similar to that described in Study 2.0. To allow for the assessment of the effects of memory strategies on long term memory including the effects of consolidation, this experiment occurred across two days. One Day 1 (Figure 1a), participants arrived at the Boston University CNC, completed informed consent, and verified that they met the eligibility requirements (see above inclusion criteria). Subjects then changed into scrubs in preparation for the scan session and completed the encoding phase on a laptop in the CNC. Participants were then given instructions for the rest of the experiment, and then immediately entered the scanner and completed the reminder and regulation phases. On Day 2 (Figure 1b), participants completed the cued recall phase remotely over Zoom. Immediately after the cued recall phase, they completed the PANAS, STAI, BDI, ERQ, and debriefing questionnaires online.



Figure 1. Paradigm for fMRI experiment. On Day 1 (a), participants completed the encoding phase outside the scanner, then the reminder and regulation phases inside the scanner. 24 hours later on Day 2 (b), they completed the cued recall and source memory tests.

Encoding Phase. On a laptop outside of the scanner, subjects watched 48 video clips (Table 5) broken into 6 blocks. 24 clips were negative (12 retrieval-only condition, 12 reappraisal condition), 12 were positive (retrieval-only condition), and 12 were neutral (retrieval-only). Each video was matched with a semantically-related, neutral cue word that appeared on the screen with the video. Participants were instructed to pay attention to the video but also to memorize each word-video pair because they would be later asked to recall the video based on the word alone. Immediately after each video clip, participants rated the valence of the video clip on a scale of 1 ('most negative') to 9 ('most positive'). They then rated the emotional intensity of the clip on a scale of 1 ('least intense') to 9 ('most intense').

valence	mean	min	max
neg	2.45	1.63	3.00
neu	5.70	4.39	6.19
pos	7.67	6.38	8.48

Table 2. Video descriptives of stimuli used in fMRI experiment.

Reminder Phase. Some analyses will compare event representations in the brain before and after regulation occurs. Thus, to provide a point of comparison before regulation, participants first viewed sets of still images taken from each video clip while fMRI data were collected. Each image set consisted of 10 images presented for 500 ms each in chronological order sampled at equal intervals relative to the duration of the video. Participants were instructed to vividly remember the video that the images are taken from during this 5 s 'image period.' After the image period, participants were shown a reminder of the cue word for 2 sec to help ensure that they would remember the cue-video pairing throughout the rest of the experiment. For each interval (ITI) throughout the experiment, participants completed an active baseline task

during which they were shown arrows and were instructed to press different buttons depending on whether the arrow was pointing left or right. Participants saw each image set once, and to keep scan runs to a reasonable duration, the reminder phase was broken up into 2 scan runs.

Regulation Phase. While fMRI data were being collected, participants then recalled each video and were instructed to either reappraise their memory of the video (half of the negative videos) or continue remembering the video naturally (rest of negative videos, plus all of the positive and neutral videos). Each trial consisted of a 'reactivation period' (5 s), 'elaboration period' (10 s), and success rating (2 s). During the reactivation period, participants were shown a cue word and an empty white box on the screen signaling that they should start to remember the video that was paired with the cue word. They were instructed to push a button when they started to remember the cued video. After 5 seconds, the white box changed to either green or blue. If the box turned green they were instructed to continue remembering the video naturally, walking through it in their 'mind's eye' for the 10 seconds that the colored box remained on the screen with the cue word. If the box turned blue (negative videos only), they were asked to reframe the video in order to render it less emotionally negative and/or more emotionally positive. When receiving instructions for the regulation phase (before getting in the scanner), participants were told that in order to reframe the negative events, they should search for a 'silver lining' (e.g., community brought together by an accident) or focus on a plausible positive outcome for the video (e.g., injured person will fully recover). There were 3 rounds of the regulation phase, meaning that each item was either remembered or reappraised 3 times. To keep scan runs at a reasonable duration, regulation rounds were broken up into 3 runs each, meaning that the regulation phase consisted of 9 scan runs total.

Cued Recall. On the following day participants completed the cued recall phase remotely using the online platform Pavlovia.org. The experimenter provided instructions via Zoom immediately before participants started cued recall. During each cued recall trial, participants were shown

each of the 48 cue words one at a time, and asked to type a description of their memory for the associated video in as much detail as they could remember. They then rated their memory vividness on a scale of 1-9 ('not at all vivid' to 'very vivid'), memory valence on a scale of 1-9 ('very negative' to 'very positive'), and memory emotional intensity ('not at all intense' to 'very intense'). After competing cued recall for all videos, participants completed a final source memory test during which they were again shown each cue word and asked to indicated whether the associated video had been in the retrieval-only condition ("remembered -- blue box video"), reappraisal condition ("reframed -- green box video"), or they didn't remember ("I don't know").

3.2.4 MRI Data Acquisition

Imaging data were collected using a 3T Siemens MAGNETOM Prisma MRI scanner with a 32channel head coil at the Boston University Cognitive Neuroscience Center. Structural MRI images were collected using a T1-weighted multi-echo MPRAGE protocol (van der Kouwe et al. 2008) (field of view = 256 mm, GRAPPA (iPAT) acceleration = 4 (Griswold et al. 2002), 1 mm isotropic voxels, 176 sagittal slices with interleaved acquisition, TR = 2530 ms, TE = 1.69/3.55/5.41/7.27 ms, flip angle = 7 degrees, anterior-to-posterior phase encoding). Functional images were acquired using a whole brain multiband (Moeller et al. 2010) echoplanar imaging (EPI) sequence (bandwidth = 1718, field of view = 208 mm, 2mm isotropic voxels, 69 slices with interleaved acquisition, TR = 1500ms, TE = 28 ms, flip angle = 75, anterior-to-posterior phase encoding) for a total of 296 TRs per scan run. Fieldmap scans were acquired at the beginning of the scan session and again after the 3rd regulation phase run to correct the EPI images for signal distortion (TR = 7 ms, TE = 0.066 ms, flip angle = 90 degrees).

3.2.5 FMRI Data Processing

FMRI data were converted to NIfTI format using dcm2nii (Li et al. 2016) and converted to Brain Imaging Data Structure (BIDS) format using custom scripts, verified using the BIDS validator: http://bids-standard.github.io/bids-validator/. MRIQC v0.15.1 (Esteban et al. 2017) was used to verify data quality. Scan runs were excluded from analyses if > 20% of time points exceeded a framewise displacement of 0.30 mm. All data preprocessing was completed using FMRIPrep v1.5.2 (Esteban et al. 2017) with the default processing steps. The data were then smoothed using an 8 mm gaussian kernel with SPM12. Six realignment parameters and five aCompCor components were also included as nuisance regressors in each model. All analyses were conducted using SPM12 (https://www.fil.ion.ucl.ac.uk/spm/software/spm12/) and custom scripts.



Figure 2. *A priori* regions of interest (visualized using BrainNet Viewer, Xia et al. 2013). Episodic memory ROI constructed from the overlap of a Neurosynth meta-analysis using the term 'episodic memory' and anatomical regions including regions in the posterior medial network (a) and anatomical occipitotemporal ROI (b).

3.2.6 Regions of Interest

Regions of interest (ROIs) included regions in a posterior medial network associated with recollection (Libby et al. 2012; Ritchey et al. 2014) and episodic processing (e.g., Ritchey and Cooper 2020). To construct a PM network ROI, I first used a Neurosynth meta-analysis (https://neurosynth.org) to construct a functional ROI of activation that is positively associated with the search term 'episodic memory.' I then assessed the overlap between this functional ROI and Schaefer Atlas (Schaefer et al. 2018) (https://github.com/ThomasYeoLab/CBIG) anatomical regions in the PM network to create my final PM network ROI (Figure 10). These regions include the hippocampus (HIPP), parahippocampal cortex (PHC), retrosplenial cortex (RSC), precuneus (PREC), angular gyrus (ANG), posterior cingulate cortex (PCC), and medial prefrontal cortex (mPFC). Additionally, I examined activity within the amygdala (AMY), a region implicated in affect and emotional memory (Mickley Steinmetz et al. 2010; Sharot et al. 2004). Finally, for representational similarity analysis, I assessed activity within an occipitotemporal cortex (OTC) ROI created from Schaefer Atlas (Schaefer et al. 2018) and based on a recent study examining feature reinstatement in OTC (Favila et al. 2018). This ROI includes regions that show reactivation of perceptual information during recall, such as V1, fusiform gyrus, collateral sulcus, and lateral occipitotemporal sulcus (O'Craven and Kanwisher 2000; Favila et al. 2018; Kark and Kensinger 2015). For completeness, reinstatement within HIPP, AMY (Bowen and Kensinger 2017), and episodic memory ROI were also assessed (see Supplemental Materials). Mean activity within ROIs was calculated as the mean voxel value bilaterally. Planned comparisons between conditions were assessed using paired t-tests within each ROI.

Whole brain contrasts were tested using a voxel-wide threshold of p < .001 and cluster corrected at p < .05 based on nonparametric permutation tests using the SnPM toolbox (nisox.org/Software/SnPM13).

3.3 ANALYSIS

3.3.1 Behavioral Analysis

Behavioral data were analyzed similarly to Study 2.0. Planned comparisons between the reappraisal and retrieval-only memory conditions were assessed using paired t-tests. To evaluate whether the effects of memory strategy on memory valence observed in Study 2.0 were replicated using the fMRI paradigm, the effects of condition on mean recall valence and item-level change in valence were tested. Corresponding secondary analyses were also conducted for emotional intensity. Additionally, to test whether the effects of memory strategy on memory quality were replicated, I evaluated the effect of strategy on percent remembered and memory accuracy. Secondary analyses were conducted to test the effect of strategy on number of details recalled and mean recall vividness. All behavioral analyses excluded trials that were not successfully regulated or retrieved. Analyses assessing the effect of strategy on valence, emotional intensity, recall vividness, and accuracy additionally excluded forgotten items (see Study 2.0 Methods).

3.3.2 Neuroimaging Analysis

Valence-Related Activity. The first set of analyses identified which brain areas are sensitive to memory valence by looking for differences in activation when remembering negative, neutral, and positive items during the regulation phase. The regulation phase was fit to a GLM with regressors of interest corresponding to each condition (reappraise-neg, retrieve-only-neg,

retrieve-neu, and retrieve-pos) for trial periods of interest (reactivation and elaboration periods). The reactivation period was modeled as a 5s block, the elaboration period was modeled as a 10s block, and the success rating period was modeled as an event (0s) as a singular regressor. Therefore, the elaboration period GLM had 9 regressors of interest. Whole brain activation associated with recalling retrieved-only negative items compared to neutral items was assessed within the reactivation period and elaboration periods. Additionally, since the amygdala has been implicated in recalling negative events, and all further analyses will focus on negative items, analogous ROI analyses within bilateral amygdala were conducted. Whole brain activation activation comparing recalling retrieved-only positive items to neutral items during the reactivation period and elaboration periods were also evaluated.

Reappraisal-Related Activity. Next, whole-brain activity related to reappraisal was assessed by determining how reappraising negative items differs from retrieving-only negative items during the elaboration period of the regulation phase. This contrast only included trials that were rated as > 1 regulation success in order to exclude trials where the video was forgotten or employment of the memory strategy (reappraisal or retrieval-only) was completely unsuccessful. Then, I assessed where whole-brain reappraisal-related activity varies with subjective reappraisal success by adding success ratings as a parametric modulator to all elaboration period regressors and evaluating the linear contrast of reappraised negative items as modulated by success ratings. I also evaluated this linear contrast compared to retrieval-only activity that varies by subject success ratings. All trials regardless of success rating were included in this contrast in order to best capture how variability in regulation success ratings relates to brain activity.

Recall-Related Activity and Valence Reduction. Next, I tested the hypothesis that recallrelated activity is positively related to reappraisal-modulated change in valence. Because this model incorporates valence ratings at cued recall, the relationship between change in valence and brain activity was not assessed for items that were forgotten at the time of cued recall. Change in valence was added as a parametric modulator to each reactivation period and elaboration period regressor for remembered items. Regressors for forgotten items from each condition were added without parametric regressors.

First, I assessed where recall-related activity during the reactivation period varies with change in valence for reappraised items by evaluating the linear contrast of reappraised items during the reactivation period modulated by change in valence. To assess whether reactivation period recall-related activity is related to change in valence differently for reappraised versus retrieved-only items, this contrast was also compared to retrieved-only negative items modulated by change in valence. Analogous analyses were conducted looking at brain activity during the elaboration period. Because regions within the PM network, hippocampus, and amygdala have been found to be implicated in episodic retrieval of emotional memories, these contrasts were also assessed by extracting mean T values from within the episodic memory ROI and anatomical hippocampal and amygdala ROIs.

Memory Reinstatement and Reduction in Negative Valence. Finally, I directly tested the hypothesis that the degree of memory reinstatement before reappraisal is positively related to a reduction in negative affect. First, I assessed whether there was reinstatement of item-level event information using representational similarity analysis. Only negative items were included in item-level reinstatement analyses. Patterns for each item from the first round of the regulation phase, before any reappraisal had occurred, were compared to patterns from the same item, and different items, in the reminder phase (Figure 3a). To remove potential sources of noise from the timeseries data, a GLM was constructed with only nuisance regressors (realignment parameters and acompcor), and the residuals from this model (one per timepoint) were then used to evaluate similarity. The onset of each timepoint was adjusted by +4 seconds to account for the hemodynamic response lag. To capture activity during the reactivation periods of the

regulation phase and reminder phase, timepoints between the adjusted onset of the period and 6sec after the onset were averaged. Therefore, for each subject, each item was associated with a single spatial pattern from the reminder phase and a single spatial pattern from the first round of the regulation phase. Analyses will be conducted using the first round of regulation as planned *a priori*, since reappraisal may change memory representations across repetitions and may therefore affect reinstatement values. Using CoSMoMVPA (Oosterhof et al. 2016), the Fisher z-transformed Pearson correlation between the spatial pattern of values from the reminder phase and each of the regulation phase rounds was then extracted from occipitotemporal cortex. The diagonals of the regulation phase with the same item from the reminder phase (*zWithin*). The off-diagonal will represent the correlation of a negative item from the regulation phase (*zBetween*). For each subject, reinstatement values were calculated for each item as the difference of the mean similarity between the item's regulation pattern and all other items' reminder patterns (i.e., the mean of the off-diagonal column values subtracted from the diagonal value):

zDifference = zWithin - zBetween

To assess whether item-level neural reinstatement is occurring within OTC, a paired t-test comparing *zWithin* to *zBetween* was run. Item-level pattern reinstatement is implied if *zWithin* is significantly higher than *zBetween* --- in other words, if items during the regulation phase are more similar to themselves during the reminder phase than other items at the reminder phase. Items with a mean success rating of 1.00 were excluded from this analysis to avoid including items that had been forgotten at the time of regulation, since reinstatement would not be expected for forgotten items. I next tested the relationship between the degree of neural reinstatement within OTC and change in valence using a linear mixed effects analysis with maximum likelihood estimate from R's Ime4 package (Bates et al. 2014). The model included

change in valence as the dependent variable and a fixed effect representing the linear effect of reinstatement value (*zDifference*). Random intercepts were included for subject and video. The p value for the fixed effect was obtained by a likelihood ratio test of the full model against a null model without the effect in question.

Because it is possible that valence-level information, rather than item-level information, is primarily reinstated before attempts to reappraise, analogous analyses to those described above were conducted at the valence category level. To accomplish this, reappraised negative items during the reactivation period of the regulation phase (first round) were compared to negative, neutral, and positive items during the reminder phase. Similarity (reinstatement) difference values were calculated as the mean similarity of same-valence trials minus the mean similarity of the different-valence trials. Valence-level reinstatement was implied if this difference value was significantly greater than 0, evaluated using a one-way t-test.

Finally, secondary analyses evaluated item- and valence-level reinstatement in the episodic memory, hippocampus, amygdala, and functional lateral occipital (see Results) regions of interest (see Supplemental Materials).



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Figure 3. Schematic representation of item reinstatement analysis (RSA). Patterns of brain activity were extracted from regions of interest (a). These patterns for items during the regulation phase were correlated with the same (orange) and different (blue) items during the reminder phase and a difference score (*zDifference*) was calculated (b).

3.4 RESULTS

3.4.1 Behavioral

Despite predictions that reappraisal would reduce negative valence, on average reappraised items were rated as slightly more negative than retrieved-only negative items at recall, t(29) = -2.58, p = 0.015 (see Table 3 for descriptive statistics). There were no other significant differences between the reappraisal and retrieval-only condition, all ps > 0.36. All together, these results suggest that reappraisal neither enhanced nor diminished long-term memory for the videos, but also did not reduce the negative affect of memories.

	reappraisal		retriev	/al-only	
measure	mean	SD	mean	SD	
recall valence	2.89	0.83	3.18	0.85	
valence change	0.17	0.74	0.37	0.74	
recall intensity	4.79	1.73	4.51	1.57	
intensity change	-1.13	1.66	-1.40	1.45	
recall vividness	5.85	1.14	5.82	1.13	
percent remembered	0.95	0.07	0.93	0.11	
total details recalled	8.21	3.27	8.21	2.77	
accuracy	0.89	0.43	0.88	0.48	

Table 3. Descriptive statistics for behavioral measures.

3.4.2 Neuroimaging

Valence-Related Activity. The first set of analyses characterized areas in the brain that were sensitive to valence information as participants remembered the videos (Table 4). Across the whole brain, remembering negative events was associated with activity within bilateral anterior insula, frontal inferior triangularis, right anterior cingulum, and right frontal medial gyrus during the reactivation period, and bilateral precuneus, right angular gyrus, and right inferior frontal and temporal regions during the elaboration period (Figure 2). Though recalling negative events has been shown to activate the amygdala in previous studies, an ROI analysis within bilateral amygdala revealed significantly greater activity for neutral (mean = 0.054, SD = 0.127) versus negative (mean = 0.015, SD = 0.128) items during the reactivation period, (t(29) = -2.49, *p* = 0.019, and no significant difference during the elaboration period, *p* = 0.257. Across the whole brain, remembering positive events was associated with right precuneus and left posterior cingulum activity during the reactivation period, and bilateral precipion, and bilateral precuneus activity during the

elaboration period (Figure 2). Together, these results show that the valence of memories modulates activity in regions associated with episodic memory, both during the initial memory reactivation phase as well as during elaboration.



Figure 4. Activity associated with retrieval-only of negative events (red), positive events (green), and their overlap (yellow) during the reactivation period (top) and elaboration period (bottom).

			MNI	Coordi	nates	
	k	Hem	x	У	z	t
pos ret-only > neu ret-only, elaboration period						
Precuneus	1090	R	5	-48	28	5.05
		L	-5	-60	44	5.02
		L	-13	-56	36	4.46
neg ret-only > neu ret-only, elaboration period						
Cerebellum	3298	L	-13	-86	-32	6.47
		R	5	-80	-36	5.50
		L	-21	-84	-22	5.19
Precuneus	1831	L	-3	-74	34	6.28
		L	-13	-60	30	4.97
		R	15	-70	38	4.73
Superior temporal sulcus	285	R	53	-14	-18	5.88
Inferior temporal gyrus		R	61	-10	-26	4.26
Middle temporal gyrus		R	69	-16	-16	3.52
Angular gyrus	1647	R	49	-52	30	5.72
		R	53	-68	40	5.47
		R	37	-72	42	5.07
Superior medial frontal gyrus	498	R	9	40	56	5.56
Superior motor area		L	-1	22	70	4.68
Superior medial frontal gyrus		L	1	30	66	4.10
Inferior frontal gyrus	593	R	53	22	38	4.70
Inferior frontal sulcus		R	45	24	30	4.29
Middle frontal gyrus		R	39	12	46	4.25
pos ret-only > neu ret-only, reactivation period						
Precuneus	713	R	3	-58	34	6.66
Posterior cingulum		L	-1	-50	24	4.31
neg ret-only > neu ret-only, reactivation period						
Anterior insula	657	L	-29	22	-2	7.78
Frontal inferior triangularis		L	-49	24	12	3.65
		L	-51	22	0	3.46
Anterior insula	1687	R	31	26	-2	7.21
Frontal inferior triangularis		R	55	22	10	5.93
Frontal inferior operculum		R	47	20	36	5.08
Frontal medial gyrus	1461	R	7	38	48	6.56
Anterior cingulum		R	7	34	32	5.96
Frontal medial gyrus		R	3	30	42	5.31
Calcarine sulcus	337	L	-13	-96	-4	4.97
Lateral occipital gyrus		L	-25	-104	0	4.38
		L	-19	-90	-14	4.28

Table 4. Whole-brain cluster-corrected results characterizing activity related to item valence.

Reappraisal-Related Activity. Next, I evaluated brain activity related to reappraisal by contrasting elaboration period activity related to reappraising negative items with activity related to retrieving negative items. As expected based on the prior literature, reappraisal was associated with widespread activation in prefrontal regions, including bilateral orbitofrontal cortex and temporal pole and left dIPFC, vIPFC, dmPFC and vmPFC (Figure 5, Table 5).There was also a large cluster encompassing the left caudate, putamen, and thalamus. Then, I assessed whether reappraisal-related activity varies with perceived success ratings in the whole brain (Table 5). There were significant clusters in right inferior temporal gyrus, left temporal pole, and left angular gyrus. There was also a large cluster within left supplementary motor cortex extending to medial frontal gyrus. When comparing reappraisal-related activity modulated by success ratings, no significant clusters survived correction, suggesting that the success-modulated results were not specific to reappraisal. Overall, reappraisal was associated with activation in control-related brain regions previously seen in memory reappraisal (Holland and Kensinger 2013), particularly dorsal and ventrolateral regions.



Figure 5. Reappraisal-related whole brain activity. During the elaboration phase, reappraisal versus retrieval-only of negative items was associated with widespread prefrontal activation.

k Hem x y z t neg reap ~ valence change > neg ret-only ~ valence change, elaboration period R 45 -86 8 4.92 Lateral occipital gyrus 329 R 45 -80 6 4.76 R 49 -80 -4 4.11 neg reap > neg ret-only, elaboration period R 51 20 -4 4.11 neg reap > neg ret-only, elaboration period L -51 24 4 12.18 Middle temporal pole L -51 24 4 11.54 Cerebellum 5470 R 33 -58 -30 9.63 Superior temporal sulcus 2170 L -51 -64 28 8.83 Angular gyrus L -41 -76 48 5.21 Cudate 1695 L -15 -64 28 8.95 Putamen L -21 2 2 6.17 Middle temporal pole				MNI Coordinates			
neg reap - valence change > neg ret-only - valence change, elaboration period R 45 -86 8 4.92 Lateral occipital gyrus 329 R 45 -80 6 4.76 R 49 -80 -4 4.11 neg reap > neg ret-only, elaboration period L -51 24 4 12.18 Middle temporal pole L -49 0 -32 11.52 Superior medial frontal gyrus L -11 58 24 9.63 Cerebellum 5470 R 33 -58 -30 9.24 Superior temporal sulcus 2170 L -51 -64 28 8.83 Angular gyrus L -11 58 10 7.74 Cudate 1695 L -15 -2 12 8.00 Putamen L -19 6 10 7.74 Middle temporal pole 2790 R 49 14 -26 7.90 Anterior insula R 53 26 6 5.78 -6 <		k	Hem	x	у	z	t
Lateral occipital gyrus 329 R 45 -86 8 4.92 R 51 -80 6 4.76 R 49 -80 -4 4.11 neg reap > neg ret-only, elaboration period R -51 24 4 12.18 Middle temporal pole L -51 24 4 11.52 Superior medial frontal gyrus L -11 58 24 11.54 Cerebellum 5470 R 33 -58 -30 9.63 Superior temporal sulcus 2170 L -51 64 28 8.83 Angular gyrus L -41 -76 48 5.21 Cudate 1695 L -15 -2 12 8.00 Putamen L -41 -76 48 5.21 0 7.74 Middle temporal pole 2790 R 49 14 -26 7.93 Cerebellum 399	neg reap ~ valence change > neg ret-only ~ valence char	nge, elaboration pe	eriod				
R 51 -80 6 4.76 R 49 -80 -4 4.11 neg reap > neg ret-only, elaboration period -81 24 4.11 Inferior frontal gyrus 27265 L -51 24 4 12.18 Middle temporal pole L -49 0 -32 11.92 Superior medial frontal gyrus L -11 58 24 11.54 Cerebellum 5470 R 33 -58 -30 9.63 Curreport temporal sulcus 2170 L -51 -64 28 8.83 Angular gyrus L -41 -76 48 5.21 Cudate 1695 L -11 52 2 6.17 Middle temporal pole 2790 R 49 14 -26 7.99 Anterior insula R 53 26 6 5.78 Cerebellum 399 R 71 -64 -32 7.03 Inferior orbitofrontal gyrus 324 R	Lateral occipital gyrus	329	R	45	-86	8	4.92
R 49 -80 -4 4.11 neg reap > neg ret-only, elaboration period			R	51	-80	6	4.76
neg reap > neg ret-only, elaboration period 27265 L -51 24 4 12.18 Middle temporal pole L -49 0 -32 11.92 Superior medial frontal gyrus L -11 58 24 11.54 Cerebellum 5470 R 33 -58 -30 9.63 Cerebellum 5470 R 33 -58 -30 9.24 Superior temporal sulcus 2170 L -51 -64 28 8.83 Angular gyrus L -41 -76 48 5.21 Cudate 1695 L -15 -2 12 8.00 Putamen L -14 -76 48 5.21 Middle temporal pole 2790 R 49 14 -26 7.99 Anterior insula R 53 26 -6 5.78 Cerebellum 399 R 7 -54 -44 7.86 Inferior orbitofrontal gyrus R 53 26 5.78 7.99			R	49	-80	-4	4.11
Inferior frontal gyrus 27265 L -51 24 4 12.18 Middle temporal pole L -49 0 -32 11.92 Superior medial frontal gyrus L -11 58 24 11.54 Cerebellum 5470 R 33 -58 -30 9.63 Cerebellum 5470 R 33 -58 -32 9.24 R 41 -60 -32 9.24 8.35 -52 9.24 Superior temporal sulcus 2170 L -51 -64 28 8.83 Angular gyrus L -41 -76 48 5.21 Cudate 1695 L -15 -2 12 8.00 Putamen L -21 -2 2 6.17 Middle temporal pole 2790 R 49 14 -26 7.99 Anterior insula R 37 24 -14 6.03 Inferior orbitofrontal gyrus 399 R 7 -54 -44 7.30	neg reap > neg ret-only, elaboration period						
Middle temporal pole L -49 0 -32 11.92 Superior medial frontal gyrus L -11 58 24 11.54 Cerebellum 5470 R 33 -58 -30 9.63 R 41 -60 -32 9.24 R 35 -62 -52 8.95 Superior temporal sulcus 2170 L -51 -64 28 8.83 Angular gyrus L -41 -76 48 5.21 -2 12 8.00 Putamen L -11 5 -2 12 8.00 Putamen L -19 6 10 7.74 Middle temporal pole 2790 R 49 14 -26 7.99 Anterior insula R 37 24 -14 6.03 Inferior orbitofrontal gyrus R 7 54 -44 7.86 Cerebellum 399 R 7 54 -44 7.03 Inferior remporal gyrus 324 <td< td=""><td>Inferior frontal gyrus</td><td>27265</td><td>L</td><td>-51</td><td>24</td><td>4</td><td>12.18</td></td<>	Inferior frontal gyrus	27265	L	-51	24	4	12.18
Superior medial frontal gyrus L -11 58 24 11.54 Cerebellum 5470 R 33 -58 -30 9.63 R 41 -60 -32 9.24 R 35 -62 -52 8.95 Superior temporal sulcus 2170 L -51 -64 28 8.83 Angular gyrus L -11 -76 48 5.21 Cudate 1695 L -15 -2 12 8.00 Putamen L -19 6 10 7.74 Middle temporal pole 2790 R 49 14 -26 7.99 Anterior insula R 37 24 -14 6.03 Inferior orbitofrontal gyrus R 73 26 -6 5.78 Cerebellum 399 R 77 -54 -44 7.86 Cerebellum 399 R -51 -14 -26 4.33 Inferior temporal gyrus 324 R -51 -14 </td <td>Middle temporal pole</td> <td></td> <td>L</td> <td>-49</td> <td>0</td> <td>-32</td> <td>11.92</td>	Middle temporal pole		L	-49	0	-32	11.92
Cerebellum 5470 R 33 -58 -30 9.63 R 41 -60 -32 9.24 R 35 -62 -52 8.95 Superior temporal sulcus 2170 L -51 -64 28 8.83 Angular gyrus L -41 -76 48 5.21 Cudate 1695 L -15 -2 12 8.00 Putamen L -11 -2 2 6.17 Middle temporal pole 2790 R 49 14 -26 7.99 Anterior insula R 37 24 -14 6.03 Inferior orbitofrontal gyrus R 73 26 -5.78 Cerebellum 399 R 7 -54 -44 7.86 Cerebellum 399 R 7 -54 -44 7.86 Inferior temporal gyrus 324 R -51 -14 -26 4.83 Temporal gyrus 324 R -51 0 -26	Superior medial frontal gyrus		L	-11	58	24	11.54
R 41 -60 -32 9.24 R 35 -62 -52 8.95 Superior temporal sulcus 2170 L -51 -64 28 8.83 Angular gyrus L -41 -76 48 5.21 Cudate 1695 L -15 -2 12 8.00 Putamen L -11 5 -2 12 8.00 Putamen L -11 6 10 7.74 Middle temporal pole 2790 R 49 14 -26 7.99 Anterior insula R 37 24 -14 6.03 Inferior orbitofrontal gyrus R 73 26 -6 5.78 Cerebellum 399 R 7 -54 -44 7.86 Inferior remporal gyrus 324 R -31 -80 -32 7.03 Inferior temporal gyrus 324 R -51 14 -26 4.85 Temporal pole L -47 12 <t< td=""><td>Cerebellum</td><td>5470</td><td>R</td><td>33</td><td>-58</td><td>-30</td><td>9.63</td></t<>	Cerebellum	5470	R	33	-58	-30	9.63
R 35 -62 -52 8.95 Superior temporal sulcus 2170 L -51 -64 28 8.83 Angular gyrus L -41 -76 48 5.21 Cudate 1695 L -15 -2 12 8.00 Putamen L -19 6 10 7.74 L -21 -2 2 6.17 Middle temporal pole 2790 R 49 14 -26 7.99 Anterior insula R 37 24 -14 6.03 Inferior orbitofrontal gyrus R 53 26 -6 5.78 Cerebellum 399 R 7 -54 -44 7.86 Cerebellum 399 R -64 -32 7.03 Inferior temporal gyrus 324 R -51 -6 4.85 Temporal pole L -47 -66 26 4.85			R	41	-60	-32	9.24
Superior temporal sulcus 2170 L -51 -64 28 8.83 Angular gyrus L -41 -76 48 5.21 Cudate 1695 L -15 -2 12 8.00 Putamen L -19 6 10 7.74 Middle temporal pole 2790 R 49 14 -26 7.99 Anterior insula R 37 24 -14 6.03 Inferior orbitofrontal gyrus R 53 26 -6 5.78 Cerebellum 399 R 7 -54 -44 7.86 Cerebellum 399 R -72 -24 7.30 Inferior orbitofrontal gyrus 324 R -51 -44 7.86 Cerebellum 399 R -7 -64 -32 7.03 Inferior temporal gyrus 324 R -51 -14 -26 4.85 Temporal pole L -47 12 -30 4.32 Inferior temporal sulcus			R	35	-62	-52	8.95
Angular gyrus L -41 -76 48 5.21 Cudate 1695 L -15 -2 12 8.00 Putamen L -19 6 10 7.74 Middle temporal pole 2790 R 49 14 -26 7.99 Anterior insula R 37 24 -14 6.03 Inferior orbitofrontal gyrus R 53 26 -6 5.78 Cerebellum 399 R 7 -54 -44 7.86 1967 L -31 -80 -32 7.78 L -23 -72 -24 7.30 L -47 -64 -32 7.03 neg reap ~ subjective success, elaboration period L -47 12 -30 4.32 Inferior temporal gyrus 324 R -51 -14 -26 4.85 Temporal pole L -47 12 -30 4.32 Superior temporal sulcus 315 L -47 66 26	Superior temporal sulcus	2170	L	-51	-64	28	8.83
Cudate 1695 L -15 -2 12 8.00 Putamen L -19 6 10 7.74 Middle temporal pole 2790 R 49 14 -26 7.99 Anterior insula R 37 24 -14 6.03 Inferior orbitofrontal gyrus R 53 26 -6 5.78 Cerebellum 399 R 7 -54 -44 7.86 1967 L -31 -80 -32 7.78 L -23 -72 -24 7.30 Inferior temporal gyrus 324 R -51 -14 -26 4.85 Temporal pole L -47 -64 -32 7.03 Inferior temporal gyrus 324 R -51 -14 -26 4.85 Temporal pole L -47 12 -30 4.32 Supperior temporal sulcus 315 L -47 12 -30 4.32 Supplementary motor area 1129 L	Angular gyrus		L	-41	-76	48	5.21
Putamen L -19 6 10 7.74 L -21 -2 2 6.17 Middle temporal pole 2790 R 49 14 -26 7.99 Anterior insula R 37 24 -14 6.03 Inferior orbitofrontal gyrus R 53 26 -6 5.78 Cerebellum 399 R 7 -54 -44 7.86 1967 L -31 -80 -32 7.78 L -23 -72 -24 7.30 L -47 -64 -32 7.03 Inferior temporal gyrus 324 R -51 -14 -26 4.85 Temporal pole L -47 12 -30 4.32 Superior temporal gyrus 324 R -51 -14 -26 4.85 Temporal pole L -47 12 -30 4.32 Superior temporal sulcus 315 L -47 58 26 3.91	Cudate	1695	L	-15	-2	12	8.00
L -21 -2 2 6.17 Middle temporal pole 2790 R 49 14 -26 7.99 Anterior insula R 37 24 -14 6.03 Inferior orbitofrontal gyrus R 53 26 -6 5.78 Cerebellum 399 R 7 -54 -44 7.86 1967 L -31 -80 -32 7.78 L -23 -72 -24 7.30 L -23 -72 -24 7.30 Inferior temporal gyrus 324 R -51 -14 -26 4.85 Temporal pole L -47 -64 -32 7.03 Inferior temporal gyrus 324 R -51 -14 -26 4.85 Temporal pole L -47 12 -30 4.32 Superior temporal sulcus 315 L -47 12 -30 4.32 Supplementary motor area 1129 L -11 22 58 <td< td=""><td>Putamen</td><td></td><td>L</td><td>-19</td><td>6</td><td>10</td><td>7.74</td></td<>	Putamen		L	-19	6	10	7.74
Middle temporal pole 2790 R 49 14 -26 7.99 Anterior insula R 37 24 -14 6.03 Inferior orbitofrontal gyrus R 53 26 -6 5.78 Cerebellum 399 R 7 -54 -44 7.86 1967 L -31 -80 -32 7.78 L -23 -72 -24 7.30 L -47 -64 -32 7.03 neg reap ~ subjective success, elaboration period L -47 -64 -32 7.03 Inferior temporal gyrus 324 R -51 -14 -26 4.85 Temporal pole L -47 12 -30 4.32 Superior temporal sulcus 315 L -47 76 26 4.63 Supplementary motor area 1129 L -11 22 58 4.61 L -7 4 64 4.59 Medial frontal gyrus L -9 48 38			L	-21	-2	2	6.17
Anterior insula R 37 24 -14 6.03 Inferior orbitofrontal gyrus R 53 26 -6 5.78 Cerebellum 399 R 7 -54 -44 7.86 1967 L -31 -80 -32 7.78 L -23 -72 -24 7.30 L -47 -64 -32 7.03 neg reap ~ subjective success, elaboration period 11 -7 -44 -26 Inferior temporal gyrus 324 R -51 -14 -26 4.85 Temporal pole L -47 12 -30 4.32 Superior temporal gyrus 315 L -47 12 -30 4.32 Supplementary motor area 1129 L -51 0 -26 4.63 Medial frontal gyrus L -77 4 64 4.59	Middle temporal pole	2790	R	49	14	-26	7.99
Inferior orbitofrontal gyrus R 53 26 -6 5.78 Cerebellum 399 R 7 -54 -44 7.86 1967 L -31 -80 -32 7.78 L -23 -72 -24 7.30 L -47 -64 -32 7.03 neg reap ~ subjective success, elaboration period 324 R -51 -14 -26 4.85 Temporal pole L -47 12 -30 4.32 Superior temporal sulcus 315 L -47 12 -30 4.32 Supplementary motor area 1129 L -11 22 58 4.61 Medial frontal gyrus L -7 4 64 4.59	Anterior insula		R	37	24	-14	6.03
Cerebellum 399 R 7 -54 -44 7.86 1967 L -31 -80 -32 7.78 L -23 -72 -24 7.30 L -47 -64 -32 7.03 neg reap ~ subjective success, elaboration period L -47 -64 -32 7.03 Inferior temporal gyrus 324 R -51 -14 -26 4.85 Temporal pole L -47 12 -30 4.32 Superior temporal sulcus 315 L -47 12 -30 4.32 Supplementary motor area 1129 L -11 22 58 4.61 Medial frontal gyrus L -9 48 38 4.51	Inferior orbitofrontal gyrus		R	53	26	-6	5.78
1967 L -31 -80 -32 7.78 L -23 -72 -24 7.30 L -47 -64 -32 7.03 neg reap ~ subjective success, elaboration period L -47 -64 -32 7.03 Inferior temporal gyrus 324 R -51 -14 -26 4.85 Temporal pole L -47 12 -30 4.32 Superior temporal sulcus 315 L -47 12 -30 4.32 Supplementary motor area 1129 L -47 -56 26 3.91 Medial frontal gyrus L -77 4 64 4.59	Cerebellum	399	R	7	-54	-44	7.86
L -23 -72 -24 7.30 L -47 -64 -32 7.03 neg reap ~ subjective success, elaboration period		1967	L	-31	-80	-32	7.78
L -47 -64 -32 7.03 neg reap ~ subjective success, elaboration period			L	-23	-72	-24	7.30
neg reap ~ subjective success, elaboration period Inferior temporal gyrus 324 R -51 -14 -26 4.85 Temporal pole L -47 12 -30 4.32 L -51 0 -26 4.23 Superior temporal sulcus 315 L -47 -66 26 4.63 Supplementary motor area 1129 L -51 26 3.91 Medial frontal gyrus L -7 4 64 4.59			L	-47	-64	-32	7.03
Inferior temporal gyrus 324 R -51 -14 -26 4.85 Temporal pole L -47 12 -30 4.32 L -51 0 -26 4.23 Superior temporal sulcus 315 L -47 -66 26 4.63 L -53 -58 26 3.91 Supplementary motor area 1129 L -11 22 58 4.61 L -7 4 64 4.59 Medial frontal gyrus L -9 48 38 4.51	neg reap ~ subjective success, elaboration period						
Temporal pole L -47 12 -30 4.32 L -51 0 -26 4.23 Superior temporal sulcus 315 L -47 -66 26 4.63 L -53 -58 26 3.91 Supplementary motor area 1129 L -11 22 58 4.61 L -7 4 64 4.59 Medial frontal gyrus L -9 48 38 4.51	Inferior temporal gyrus	324	R	-51	-14	-26	4.85
L -51 0 -26 4.23 Superior temporal sulcus 315 L -47 -66 26 4.63 L -53 -58 26 3.91 Supplementary motor area 1129 L -11 22 58 4.61 L -7 4 64 4.59 Medial frontal gyrus L -9 48 38 4.51	Temporal pole		L	-47	12	-30	4.32
Superior temporal sulcus 315 L -47 -66 26 4.63 L -53 -58 26 3.91 Supplementary motor area 1129 L -11 22 58 4.61 L -77 4 64 4.59 Medial frontal gyrus L -9 48 38 4.51			L	-51	0	-26	4.23
L -53 -58 26 3.91 Supplementary motor area 1129 L -11 22 58 4.61 L -7 4 64 4.59 Medial frontal gyrus L -9 48 38 4.51	Superior temporal sulcus	315	L	-47	-66	26	4.63
Supplementary motor area 1129 L -11 22 58 4.61 L -7 4 64 4.59 Medial frontal gyrus L -9 48 38 4.51			L	-53	-58	26	3.91
L -7 4 64 4.59 Medial frontal gyrus L -9 48 38 4 51	Supplementary motor area	1129	L	-11	22	58	4.61
Medial frontal gyrus			L	-7	4	64	4.59
	Medial frontal gyrus		L	-9	48	38	4.51

Table 5. Whole brain cluster-corrected results for reappraisal contrasts.

Recall-Related Activity and Valence Reduction. The next set of analyses tested the hypothesis that recall-related activity during the reactivation period (before engaging in reappraisal) is positively related to reappraisal-modulated changes in valence. When comparing

recall-related activity before reappraisal that was modulated by change in valence to recallrelated activity before retrieval-only that was modulated by change in valence, there were significant clusters in right lateral occipital regions revealed by the contrast (Figure 6, Table 5), suggesting that recall-related activity in this region was more strongly related to valence change in the reappraisal versus retrieval-only condition. However, there were no clusters that were significantly related to change in valence for the reappraisal condition alone, indicating that this effect was driven by a modest positive relationship in the reappraisal condition and a modest negative relationship in the retrieval-only condition (Figure 6B). In other words, increased activation of areas associated with recalling negative events before attempts to reappraise, compared to retrieval-only, were associated with a greater reduction in the negative valence of events when they were recalled 24 hours after reappraisal occurred.

When looking within the elaboration phase, no significant clusters survived correction when comparing activity during reappraisal as modulated by change in valence to activity during retrieval-only as modulated by change in valence. To take a more targeted approach, I then tested whether the relationship between reactivation period activity and a change in valence differed for reappraisal versus retrieval-only within the amygdala, hippocampus, and episodic memory regions of interest. However, there were no significant differences between reappraisal as modulated by change in valence and retrieval-only as modulated by change in valence in any of the *a priori* ROIs, ps > 0.42.



Figure 6. During the reactivation period, whole brain activity in right lateral occipital cortex (a) was associated with reappraising modulated by change in valence compared to activity associated with retrieval-only modulated by change in valence. (b) This effect was driven by a modest positive relationship for reappraised items and a modest negative relationship for negative retrieved-only items.

Memory Reinstatement and Reduction in Negative Valence. The final set of analyses used representational similarity analysis to directly test the hypothesis that the degree of memory reinstatement during recall is related to a reduction in negative valence. We initially tested whether OTC showed evidence for item-level reinstatement. As expected, *zWithin* (mean = 0.091, SD = 0.091) was significantly greater than *zBetween* (mean = 0.071, SD = 0.082, t(29) =
2.60, p = 0.015, indicating that item-specific patterns were reinstated in OTC as participants brought negative memories to mind prior to reappraisal.

Next, I tested the relationship between the extent of reinstatement of reappraised items in occipitotemporal cortex and the change in valence. The linear fixed effect representing item reinstatement did not uniquely contribute to model fit, $\chi^2 = 0.57$, p = 0.45, meaning that there was no significant relationship between reinstatement and change in valence for reappraised items. Together, these results show that items were reinstated in occipitotemporal cortex, but this reinstatement was not related to a reduction in negative valence for reappraised items.

As a final analysis, we tested the possibility that reinstating generalized valence information, rather than item-level information, is more related to a reduction in valence. In other words, because it is the valence that reappraisal aims to modulate, perhaps the emotionality of the memory is the most critical component of that memory to reinstate prior to reappraisal, not the item-specific details. Therefore, we next assessed valence category reinstatement in occipitotemporal cortex. The measure of valence category reinstatement, *zDifference*, was not significantly greater than 0, p = 0.168), meaning that reactivation period patterns during the regulation phase for negative reappraised items were no more similar to reminder-phase patterns for negative retrieved-only items than patterns for neutral or positive retrieved-only items. Therefore, it is unlikely that reinstating generalized valence information in OTC is related to reappraisal success.

3.5 SUMMARY & CONCLUSIONS

The current study used fMRI to test the relationship between recall-related brain activity and reappraisal-mediated reductions in negative memory valence. We found that memory reappraisal was related to prefrontal activation, particularly within dIPFC, dmPFC, and vIPFC,

consistent with prior research on autobiographical memory reappraisal (Holland and Kensinger 2013). Subjective ratings of reappraisal success were also modulated by activity in supplementary motor cortex, consistent with prior studies finding an association between activity in this region and emotion regulation success (Wager et al. 2008; Kohn et al. 2014). As memories were reactivated, activation in a lateral occipital area was associated with a reappraisal-mediated reduction in negative valence 24 hours later. During the reactivation period, we observed item-level reinstatement in occipitotemporal cortex, converging with prior work showing reinstatement for emotional items in this region modulated by memory (Ritchey et al. 2013; Kark and Kensinger 2015). However, contrary to predictions, item-level reinstatement observed in the lateral occipital cortex. Together, these findings suggest that reappraisal of emotional memories engages similar networks of brain regions as have been reported for other forms of reappraisal, and that the success of memory reappraisal (i.e., reductions in negative valence) is related to the recall-related processes in the lateral occipital cortex.

4.0 DISCUSSION

A single unpleasant event can cause the reexperience of negative emotions each time it is remembered. Therefore, updating a memory to render it less negative could reduce the burden of repeated emotion regulation. However, little is known about the mechanisms supporting the lasting emotion regulation of episodic memories. Across three experiments, the current project aimed to test the behavioral and neural correlates of successfully regulating naturalistic negative memories, finding that reappraisal is associated with lasting reductions in the negative valence of naturalistic emotional memories, and these effects may be mediated by recall-related processes in lateral occipital regions.

4.1 VIDEO STIMULI CONSIDERATIONS

Naturalistic video stimuli have been increasingly used to investigate the cognitive and neural processes involved in representing dynamic events. However, previous studies have not systematically manipulated or characterized the emotional content of such videos. Therefore, we developed a database of naturalistic emotional stimuli optimized for use in emotional memory research. Because these stimuli are multimodal and depict real-life emotional events, applying emotion regulation strategies to these stimuli may closely replicate the way these strategies are naturally employed in everyday life. Overall, participants rated the videos as varying widely along the spectrum of valence, which makes these videos ideal for studies examining differential effects of positive and negative emotion. Because valence and emotional intensity were rated as separate measures, these videos can also be used to examine differential effects of these variables.

Through our analyses focused on relationships among the measures, this study also provided some interesting qualitative observations. For example, the video containing the largest deviation in dynamic valence was also the video remember most vividly. This particular clip showed a young girl standing on a toilet, which initially seems humorous. However, it was later revealed that she is demonstrating what she was taught to do during an active shooter drill at her preschool. The video with the most negative mean summary valence was also the video with the most negative mean peak: a report that white police officers who had beaten a black motorcyclist were acquitted by an all-white jury. Likewise, the video with the most positive mean summary valence also had the most positive mean peak: footage of an excited dog greeting a soldier who had just returned home. This exemplifies the strong relationship between peak valence and summary valence. These observations call to mind questions about which parts of episodic memories are important to regulate for a lasting change in valence -- for example, is it only content from the most negative peak of an event that must be reappraised, or does the

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entire event need to be recalled and updated? Future work using this video database could utilize the dynamic valence ratings to fine-tune our understanding of how emotion regulation is used during prolonged events.

Several database characteristics should be considered when interpreting the findings described and deciding whether this stimulus set is appropriate to answer a particular research question. These videos contain third person ("some-thing terrible happened") versus first person ("something terrible happened to me") emotional experiences, and thus perspective and selfrelevancy should be taken into account as factors that may modulate memory. Recalling memories from a first-person perspective is related to greater memory vividness, detail, and coherence (Sutin & Robins, 2010), and differentially recruits regions in prefrontal cortex (St Jacques, Conway, Lowder, & Cabeza, 2011). Self-relevant content also tends to be remembered better than self-irrelevant content (Rogers, Kuiper, & Kirker, 1977) and is associated with increased activity in medial prefrontal cortex and cingulate cortex during retrieval (Kelley et al.,2002). Thus, it should be considered that employing emotion regulation strategies while recalling these events may not engage the same cognitive or neural mechanisms as recalling an autobiographical event. However, the activation we observed during memory reappraisal of the news video events was similar to that observed in a study of autobiographical memory reappraisal (Holland and Kensinger 2013), suggesting that the processes are comparable. It should also be noted that first-person emotional events are not necessarily self-relevant (e.g., observing something happening to some-one else), that third-person emotional events can be self-relevant (e.g., death of a celebrity one identifies with), and that third-person emotional events are frequently and naturally experienced via news broadcasts (e.g., celebrity death, mass shooting, natural disaster). Thus, these stimuli replicate some naturally occurring emotional experiences, but may not generalize to all emotional experiences.

Our video stimuli build upon existing video stimulus databases in several ways. First, this set includes more stimuli than comparable databases. This is particularly important for experiments that require analyses to be focused on a subset of the data—for example, memory experiments like Studies 2.0 and 3.0 that compare remembered items between valence categories. Additionally, each video can be treated as a discrete event, or videos can be played sequentially like a news broadcast in order to create a longer event that is emotionally variable yet thematically cohesive. We have also provided information about video familiarity and semantic descriptions so that researchers can easily select the stimuli that are most appropriate for their studies. Finally, this video stimulus set is, to our knowledge, the first of its kind to provide dynamic valence ratings of real-world emotional events. As such, it can facilitate examination of the neural and cognitive processes underlying dynamic, naturalistic experiences. In particular, these stimuli are advantageous for memory experiments because their complexity and narrative structure can promote richly detailed recall.

4.2 BEHAVIORAL EFFECTS OF REGULATING EMOTIONAL MEMORIES

After developing a database of naturalistic videos optimized to study emotional memory, we used these stimuli to examine the effects of memory reappraisal and memory suppression on the emotionality, accessibility, and quality of emotional episodic memories. Prior research on emotion regulation strategies has demonstrated that employing cognitive reappraisal can reduce unpleasant feelings while experiencing (Hayes et al. 2006; Ochsner et al. 2002; Gross 1998) or remembering (Holland and Kensinger 2013; Holland and Kensinger 2013) a negative event, and may continue to influence memory emotionality even when no emotion regulation is employed (Holland and Kensinger 2013). Here, we extend these findings by showing that cognitive reappraisal has an extended effect on emotional memories, such that repeatedly engaging in memory reappraisal reduces the negative emotionality of an event when it is recalled on the following day. Our results also build upon numerous studies that have found

reappraisal during ongoing events to be considerably more effective at reducing negative affect than expressive suppression, the deliberate concealment of outward emotional expression (Richards and Gross 2000; Ochsner et al. 2002; Gross and John 2003; Dillon et al. 2007; Hayes et al. 2006).

Interestingly, we found that reappraisal impacted the perceived valence of memories without modulating the emotional intensity. Studies exploring the effects of emotion regulation vary in their measure of emotional impact, with some finding effects of regulation on valence (Dillon and Pizzagalli 2013; Kanske et al. 2012) and others on arousal (Hofmann et al. 2009; Holland and Kensinger 2013; Ochsner et al. 2002; Ochsner et al. 2004). Our reappraisal results are consistent with a study on the memory reappraisal of autobiographical memories that found memories that had been reappraised were later associated with reduced negative valence, but not emotional intensity, compared to memories that were simply recalled (Holland and Kensinger 2013). One potential explanation for this pattern of results is that memory reappraisal initially modulates semantic valence (for review see Itkes and Kron 2019) to change the appraisal of a negative event (Ochsner and Gross 2005; Sheppes et al. 2014), without necessarily immediately altering experiential emotional arousal. For example, remembering a house fire might induce emotional arousal even after memory reappraisal, but having updated the memory with the information that no one was injured might reduce explicit valence appraisals. Given that participants engaged in regulation during recall only three times over the course of a short session, perhaps more repetitions of memory reappraisal are necessary to actually reduce experiential emotional arousal. We also observed a drop in arousal from encoding to retrieval across conditions, which may be due to the fact that the events were not traumatic or highly self-relevant (Pace-Schott et al. 2011). It is possible that this drop resulted in an overall dampening effect of arousal responses, contributing to the lack of modulation associated with reappraisal. In contrast, we found that suppression reduced the emotional

intensity of items less than not retrieving the memories. While the greater reduction in arousal for not-retrieved memories appears to be partially driven by the fact that remembered videos in this condition tended to be more arousing, this finding may also suggest that, not only is suppression an ineffective strategy to modulate emotional memories, but may actually be counterproductive. The latter interpretation converges with studies showing that memory suppression can counterintuitively increase unwanted memory intrusions (Dalgleish et al. 2009; Dalgleish and Yiend 2006)-- evidence for a rebound effect that is consistent with the idea that memory suppression is not an effective emotion regulation strategy. However, we did not observe the effect of suppression sometimes found using think/no-think paradigms in which recall for suppressed items is reduced more than items that were not retrieved at all. One reason we might not have observed this effect is that studies on memory suppression typically use more simplistic stimuli such as words or static images, whereas the stimuli in this experiment consisted of complex video clips with extensive storylines, which may have been more difficult to fully suppress than stimuli typically used in other studies (e.g., Levy and Anderson 2002; Gagnepain et al. 2017). Furthermore, the dynamic memory cues may have been sufficiently strong reminders to make full suppression difficult (Ritvo et al. 2019).In addition, prior studies finding suppression effects typically involve significantly more repetitions (e.g., Joormann et al. 2005), and thus it is possible that three rounds of regulation were not sufficient to produce below-baseline suppression effects (Depue et al. 2006). It is also possible that the retrieval cue was too strong for memory suppression to be effective. In summary, three repetitions of reappraisal, but not suppression, was sufficient to reduce the emotionality of negative episodic memories.

Though negative memories can reinstate unpleasant emotions, they often carry important information that keeps us safe. From this perspective, our findings suggest that memory reappraisal might be an ideal emotion regulation strategy in that it reduces the emotionality

associated with aversive memories while maintaining memory for potentially relevant details. While prior research on emotional memory modification has largely focused on diminishing negative memories using techniques such as extinction (Rescorla and Heth 1975; Gale et al. 2004; Rachman 1989) and reconsolidation processes (Nader et al. 2000; Monfils et al. 2009), completely forgetting a negative event may not be adaptive. For example, if you are hurt by a particular person or in a specific place, it is prudent that you use caution during future encounters. Furthermore, emotional memories are extremely enduring (Christianson and Loftus 1990; Yonelinas and Ritchey 2015), and thus it is unlikely the memory of a highly salient life event would be completely forgotten. Therefore, it may be optimal to use a strategy that changes the emotionality of a memory when it is recalled, rather than rely on a strategy that is dependent on forgetting. In other words, the 'best case scenario' for dealing with an unpleasant or traumatic memory may be to reduce the negative affect associated with recalling the event to the extent that the memory can be processed and accessed without causing excessive distress or pathology.

4.2.1 Potential role of reactivation in regulating emotional memories

One notable difference between memory reappraisal and memory suppression is the degree of memory reactivation that occurs during the employment of these strategies. While memory suppression deliberately avoids strong memory reactivation, memory reappraisal requires strong reactivation in order for event details to be evaluated and appraised. Our results are consistent with a growing body of fear conditioning research demonstrating that reactivation is critical for memory modification (Nadel et al. 2012; Hupbach et al. 2013). Though fear memories are typically resistant to forgetting (Rescorla and Heth 1975; Gale et al. 2004; Rachman 1989), presenting a reminder of the conditioned stimulus before memory interventions like extinction (Schiller et al. 2010; Monfils et al. 2009) or protein synthesis inhibitor administration (Nader et al. 2000; Kindt et al. 2009) destabilizes the memory and allows for complete abolishment of the

fear response. There is also evidence that reactivation can render emotional episodic memories labile and vulnerable to editing or forgetting (for review see Samide and Ritchey 2020). One recent study demonstrated that partially reactivating memories for aversive images before employing a spatial distancing emotion regulation strategy reduced associated emotional arousal more than reactivation alone (Parikh et al. 2019). While there are considerable challenges to directly applying these techniques to modifying complex autobiographical memories (Phelps and Hofmann 2019), here, we demonstrate that engaging memory reactivation through memory reappraisal can change the emotionality of a memory. In turn, our results support the idea that reactivation may play a critical role in modifying naturalistic emotional episodic memories (Samide and Ritchey 2020). In particular, lateral occipital cortex, which is involved in recalling negatively valenced content, may facilitate a lasting reduction of negative memory valence. Our findings further harmonize with the efficacy of cognitive treatments for affective disorders that leverage reappraisal-like processes that involve recalling and addressing prior traumatic events (e.g., cognitive behavioral therapy, Butler et al. 2006). Additionally, our results parallel evidence that habitual memory suppression is associated with unwanted thought intrusions in depression (Wenzlaff et al. 1988; Geraerts et al. 2006), rumination in response to stressful events (Wenzlaff and Luxton 2003), consistent with the idea that suppression does not modify the emotionality of memories in the long-term. Overall, the behavioral findings from Study 2.0 provide evidence that, upon recall, emotional episodic memories can be modified using techniques that have been shown to reduce negative affect elicited by ongoing internal or external events.

While the current study suggests that memory reappraisal has a lasting effect on memory emotionality that persists for at least 24 hours, the extent to which people continued to engage in regulation during cued recall, even though they were not instructed to do so, is unknown. Participants occasionally included information from the provided reappraisals in their cued recall descriptions, likely accounting for the numeric but non-significant difference in accuracy between reappraised and retrieved-only memories, but this did not happen frequently enough to meaningfully quantify. Additionally, it is also possible that participants sometimes remembered which videos were in the reappraisal condition and rated them as less negative during cued recall in order to conform to what they anticipated were the experimenters' expectations. Though we cannot address this issue with data from the behavioral study (Study 2.0), we did administer a source memory test after cued recall on Day 2 of the fMRI experiment (Study 3.0), which indicated that participants were barely above chance when attempting to remember which strategy they had used the day prior (see Supplemental Materials). Additionally, participants could have equally hypothesized that suppression was meant to reduce negative emotionality. Furthermore, if the effects of reappraisal were due to participant conformity, we might also expect there to be an effect of strategy on arousal, which we did not observe. Thus, it seems unlikely that the effects of reappraisal are due to participants remembering which items had been reappraised, and purposefully adjusting valence ratings at recall accordingly.

4.2.2 Potential Limitations of Reappraisal

In contrast to the striking behavioral results observed in Study 2.0, we did not find that memory reappraisal reduced negative valence in Study 3.0. There are several external factors that may have impacted the behavioral effect of reappraisal in the fMRI study. One factor may have been the impact of the COVID-19 pandemic, during which these fMRI data were collected. Since participants were likely under more environmental stress (Hawes et al. 2021; Thompson et al. 2021; Bäuerle et al. 2020) than during the behavioral study (which was completed prior to the pandemic), and stress makes regulation more difficult (Raio et al. 2013), it is possible that reappraisal was less effective at reducing negative affect, it was more difficult to employ, or

perhaps more reappraisal repetitions were needed in order to observe a significant behavioral difference. In support of the impact of COVID on this study, the valence of negative videos was rated significantly more positive in the fMRI study than in the behavioral or video norming study (see Supplemental Materials). This may be due to the near-constant barrage of extremely negative news during the pandemic. Compounding these factors, many of the subjects were entering an MRI scanner for the first time, which may have been stressful, or at the very least, distracting. In order to sense an effect of reappraisal on valence, a more sensitive scale of valence may be useful in the future. For this study, we chose to use a 5-point scale so that a single hand could be used to make responses in the scanner in order to avoid the complexity (for participants) of mapping the scales across two hands. We are currently running a behavioral replication of Study 2.0 to ascertain whether the results can be reproduced outside of the scanning environment.

4.3 NEURAL CORRELATES OF MEMORY REAPPRAISAL

Finally, using fMRI, we tested the relationship between recall-related brain activity and reappraisal-mediated reduction in negative memory valence. While there has been extensive research on the mechanisms supporting the reappraisal of ongoing events, relatively fewer studies have focused on reappraisal during recall. Consistent with prior studies on memory reappraisal of naturalistic events (Holland and Kensinger 2013), memory reappraisal was related to prefrontal activation, particularly within dIPFC, dmPFC, and vIPFC. We also found that activity in supplementary motor cortex during the elaboration period varied with subjective ratings of retrieval success, replicating prior work showing a positive relationship between emotion regulation success and activity within this region (Wager et al. 2008; Kohn et al. 2014). Altogether, we found that activation associated with memory reappraisal largely aligned with activity generally observed during the reappraisal of ongoing events.

4.3.1 Lateral occipital activation and change in valence

This study builds upon prior research on memory reappraisal by relating activation during memory recall to a lasting effect of memory reappraisal. We found that activity in lateral occipital cortex was positively associated with a reduction in negative valence for reappraised items 24 hours after reappraisal occurred. Voxels within lateral occipital cortex have been shown to represent the valence category of affective images (Kark and Kensinger 2015) and movie trailers, even tracking with self-reported valence and arousal during trailer-watching (Chan et al. 2020). Thus, to the extent that activation in this region may indicate recapitulation of negative content (Bowen et al. 2018), our results are consistent with the hypothesis that reactivating negative memories is important for lasting reappraisal effects.

Despite finding brain activity that varied with a reappraisal-mediated reduction in valence, we did not find a behavioral effect of reappraisal on valence as described in Study 2.0. Taken together, these discordant findings may suggest that reappraisal lowered the negative valence of some memories, but not robustly or consistently enough for us to observe a significant effect of reappraisal on mean recall valence or item-level change in valence. However, for those items that did become less negative after reappraisal, this change in valence varied with activation in lateral occipital cortex.

4.3.2 Item reinstatement

During the regulation phase, we found that patterns of brain activation were more similar to patterns of activation during the reminder phase for the same item versus different items, indicating that there was item-level reinstatement within occipitotemporal cortex. Previous work has shown that this region represents item features during perception and memory (Favila et al. 2018) and the details of complex naturalistic stimuli, such as movies, during recall (Chen et al. 2017). Thus, the observed item reinstatement is consistent with prior work showing that

occipitotemporal cortex represents naturalistic memories and that encoding-retrieval pattern similarity for scenes scales with memory success within occipitotemporal cortex (Wing et al. 2015; Ritchey et al. 2013). The observation of item reinstatement specifically for negative items is also supported by prior work showing robust reinstatement of negative scenes within midoccipital (Ritchey et al. 2013) and ventral occipitotemporal regions (Kark and Kensinger 2015).

However, in contrast to our hypothesis that the extent of memory reactivation immediately prior to reappraisal attempts should facilitate lasting valence changes, we did not find any relationship between item reinstatement and a reduction in negative valence for reappraised items. This was surprising, considering that previous findings that memory reactivation immediately prior to updating is crucial for lasting memory modification (Schiller et al. 2010; Agren et al. 2012). Several possibilities exist for why we did not find the expected effect of reinstatement on change in valence. The first possibility is that there is some relationship between the extent of event reinstatement and reappraisal success, but we were unable to observe the effect in our study. One reason for this could be that it is reactivation of only very specific memory content that is crucial for updating memory valence -- for example, visual information representing a particularly negative moment within the video. If this is the case, looking for reactivation of a relatively long, multimodal event may not be sensitive enough to identify the relationship between reactivation of a particular part of the memory and a reduction in negative valence. An alternative possibility is that the relationship between reactivation and memory updating is different for naturalistic episodic memories than it is for the types of stimuli typically used in studies of memory reconsolidation and updating. For example, prior studies that have found a relationship between reactivation and memory updating have used associative memories like fear conditioning (Schiller et al. 2010) or written stories (Kroes et al. 2014). Because multimodal episodic memories contain such complex content, including audiovisual, semantic, temporal, and contextual information, they are represented by a broad

network of regions (for review see Ranganath and Ritchey 2012). Thus, because naturalistic emotional episodic memories are incredibly strong, detailed, and cognitively and neurally interconnected with related experiences and concepts, reactivation may not be sufficient to induce representational flexibility.

Another factor to consider is the timing of reappraisal attempts compared to memory recall. One framework of the temporal aspects of emotion regulation suggests that reappraisal is most effective when employed before the emotional intensity of a memory has been fully reactivated (for review see Sheppes and Gross 2011). Indeed, prior studies on autobiographical memory reappraisal found the greatest effects of using reappraisal to decrease negative emotions occurred immediately after memory onset rather than during a subsequent elaboration phase (Holland and Kensinger 2013). Thus, by having participants recall events before attempting to reappraise, it is possible that the valence or emotional intensity of memories was reinstated to the extent that reappraisal was no longer effective. For example, prior work examining the relationship between memory reactivation and modification has found that modest reactivation, but not weak or strong reactivation, facilitates updating (Lewis-Peacock and Norman 2014; Newman and Norman 2010; Detre et al. 2013). This explanation converges with the lack of relationship found between the extent of item reinstatement and a reduction in negative memory valence, as well as the lack of a behavioral effect of reappraisal because, in some cases, strong memory reinstatement of negative content may have inhibited effective reappraisal. Thus, future work is needed to fine-tune our understanding of whether and how reinstatement relates to episodic memory modification.

4.4 FUTURE DIRECTIONS & CONCLUDING THOUGHTS

Across three studies, I have developed a stimulus database that was used to test the behavioral effects and neural correlates of lasting emotion regulation of episodic memories. Altogether, my findings suggest that reappraisal maintains the accessibility and accuracy of naturalistic memories, and can result in a lasting reduction of negative memory valence. Results from our neuroimaging study suggest that this reduction is related to activation in regions that represent negative valence. However, reappraisal may only reduce memory valence under certain circumstances. Future work is needed to assess the efficacy of memory reappraisal under conditions of increased stress, anxiety, and distraction. Additionally, the timing of reappraisal relative to memory reactivation may have an impact on both behavioral and neural correlates. It is also still unclear how the timing of emotion regulation relative to encoding, sleep, and postregulation retrieval may influence the efficacy of regulation. For example, the current study involved regulating memories shortly after encoding, without allowing for sleep-facilitated consolidation processes to occur. While there is some evidence to suggest that reappraisal can update remote autobiographical memories (Holland and Kensinger 2013), the longer term effects of these strategies on the accuracy and detail of older memories is still largely unknown. And, because memory was tested on the following day, it is unknown how long the effects of memory reappraisal may last. The effects of regulation during recall on other qualitative differences between emotional and neutral memories, such as the item-context trade-off, are also unknown (Steinberger et al. 2011; Steinmetz and Kensinger 2013). Future work could also investigate whether the efficacy of the strategy varies by specific reappraisal instruction -- for example, if using distancing techniques (c.f. Parikh et al. 2019) are as effective as finding a silver lining or imagining a positive outcome. Thus, while the current work has contributed to our knowledge of memory reappraisal, there is still much to be understood about how we can change complex emotional episodic memories.

S.0 SUPPLEMENTAL MATERIALS

S.1 ITEM REINSTATEMENT IN ADDITIONAL REGIONS OF INTEREST

A paired t-test comparing *zWithin* versus *zBetween* within the episodic memory ROI revealed a nonsignificant trend towards reinstatement, t(29) = 1.80, p = 0.08. However, because no significant item-level reinstatement was found, no further analyses were conducted. There was no significant item-level reinstatement in AMY, HIPP, or the functional lateral occipital cortex ROI (see Results), ps > 0.472.

strategy	mean % correct	SD
reappraise	0.65	0.18
retrieval-only	0.58	0.26

Table S2. Source memory accuracy for memory strategy from fMRI study. Source memory was assessed for 15 subjects. After the cued recall task on Day 2, participants were again presented with the cue words and asked to respond with whether they had been asked to 'reframe' (reappraise) or 'remember' (retrieve-only) the video the prior day, or if they 'don't know.' Source memory performance was above chance for reappraised items, t(14) = 2.293, p = .019, but not retrieved-only items, p = 0.117.

S.3 AFFECTIVE RATINGS ACROSS STUDIES

	valence		arousal			
study	min	max	mean	min	max	mean
video	1.63	3.00	2.46	4.25	6.44	5.49
behav	1.80	3.20	2.37	4.37	7.04	5.69
fmri	1.79	3.72	2.88	4.69	7.03	5.88

Table S3. Descriptive statistics for valence and emotional intensity ratings for the same negative videos across Studies 1.0 (video), 2.0 (behav), and 3.0 (fmri). Twenty-two negative videos were shared across the three studies.



Figure S1. Mean recall valence ratings for the same 22 negative videos across Studies 1.0-3.0. There was a main effect of study on ratings, F(2,42) = 27.79, p < 0.001. Paired t-tests revealed that these videos were rated as significantly less negative during the fMRI study compared to during the video study (t(21) = 2.91, p = .008) and during the behavioral study, t(21) = 6.65, p < .001. ** = p < .01, *** = p < .001.

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