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REVIEW

Reframing the Past: Role of Memory Processes in Emotion Regulation

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Abstract

Background The ability to modulate undesirable emotions is essential for maintaining mental health. Negative emotions can arise both while experiencing and remembering an unpleasant event, which presents a persistent emotion regulation challenge because emotional memories tend to be particularly vivid and enduring. Despite the central role that memories play in our affective lives, little is known about the memory processes supporting successful regulation of emotions associated with long-term memories, which we refer to as retrospective emotion regulation.

Methods In this paper, we review the literature on the mechanisms of memory modification, which may contribute to the success of retrospective emotion regulation. In particular, we review rodent and human studies that examine the modification of conditioned fear associations and emotional episodic memories.

Conclusions Based on this literature, we conclude that memory reactivation plays a crucial role in memory modification. We discuss further the potential role of memory reactivation in mediating the success of cognitive reappraisal, which may be considered a special case of memory modification. We propose that the completeness, or strength, of reactivation during retrospective emotion regulation will be related to the likelihood of updating an episodic memory, reducing its emotional impact upon later recall. Understanding the role of memory processes in emotion regulation can help to inform research on memory-based treatments for affective disorders.

Keywords Emotion regulation · Cognitive reappraisal · Episodic memory · Fear extinction · Reactivation · Reconsolidation

Introduction

The ability to appropriately regulate emotions is critical for maintaining mental health (Gross and Muñoz 1995). When an unwanted emotion is triggered, control may be exerted over different cognitive processes in an attempt to reduce the unpleasant feeling. For example, internal or external attention can be reallocated to reduce awareness of the triggering stimulus, cognitive appraisals can modulate the emotional significance, and inward or outward emotional responses can be tempered (Ochsner et al. 2012). 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 (Christianson and Loftus 1990; Sheldon and Levine 2013; Yonelinas and Ritchey 2015), and thus negative memories can create a persistent emotion regulation challenge. Memory and affective symptoms are intertwined in many psychiatric disorders, including anxiety and depression (Elzinga and Bremner 2002)—for example, both ruminative memory patterns (Harrington and Blankenship 2002; Nolen-Hoeksema et al. 2008) and habitual emotion regulation strategies (Blalock and Joiner 2000; Holahan et al. 2005; Kashdan and Breen 2008; Aldao et al. 2010) are related to mental health outcomes. Yet, though clinical psychology has long leveraged memory processes in order to analyze or explore past experiences using treatments such as psychodynamic therapy (Luborsky 1977; Schafer 1980), memory specificity training (Neshat-Doost et al. 2013; Moradi et al. 2014; Eigenhuis et al. 2017), and exposure therapy (Foa et al. 1995; van Minnen et al. 2002), 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

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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. In this review, we focus on strategies based on cognitive reappraisal, which seeks to deliberately reinterpret and update a remembered experience to render it less emotionally negative (Kross et al. 2009; Holland and Kensinger 2013a). Though the cognitive processes supporting online reappraisal (i.e., reappraisal of ongoing experiences) have been extensively studied, the episodic memory mechanisms involved in facilitating successful *retrospective reappraisal*, the reappraisal of negative memories, are largely unknown. Though the 'goals' of online and retrospective reappraisal are the same (to regulate the emotion associated with an event), the reappraisal 'target' (i.e., an ongoing versus past event) could significantly impact the neural processes that support effective reappraisal. For example, whereas online reappraisal embeds the appraisal-related information into the original event representation, retrospective reappraisal necessitates the engagement of memory processes specific for updating an already existing event representation. Here, we 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, we conclude that memory reactivation plays a role in facilitating the kinds of long-lasting memory changes that are likely to support successful retrospective reappraisal. Taking a novel perspective, we will consider retrospective reappraisal as a special case of memory modification that leverages reconstructive memory processes to alter emotional episodic memories and improve mental health.

Mechanisms of Emotional Memory Modification

In the context of retrospective 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, we 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). Whereas cued fear memories are stored in the amygdala, contextual fear memories are additionally supported by the hippocampus (Rudy and O'Reilly 1999), as evidenced by studies showing hippocampal damage affects contextual fear conditioning but not cued fear conditioning (Selden et al. 1991; Phillips and LeDoux 1992). Functional magnetic resonance imaging (fMRI) suggest that the neural circuits underlying cued fear conditioning (Büchel et al. 1998; LaBar et al. 1998; Cheng et al. 2003; Knight et al. 2004; Phelps et al. 2004; Hermans et al. 2013) and contextual fear conditioning (Ji and Maren 2007; Alvarez et al. 2008; Marschner et al. 2008; Lonsdorf et al. 2014; 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 (Rescorla and Heth 1975; Gale et al. 2004). 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). In addition to reducing fear responses in both rodents (Myers and Davis 2007) and humans (Quirk et al. 2010), extinction training has been shown to reduce amygdala activity elicited by a CS (LaBar et al. 1998; Phelps et al. 2004) in humans. It is thought that extinction training works by creating a new memory trace in which the CS is safe, which is then retrieved rather than the fear memory of the CS (Bouton 1991). 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 (for review see 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 (for reviews see Nadel et al. 2012; Hupbach et al. 2013). 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.

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 without the use of a pharmaceutical intervention (Monfils et al. 2009). Indeed, reactivating a conditioned fear memory in humans by re-presenting a tone that had been paired with a shock 10 min before, but not 6 h after, extinction training reduced fear responses to the CS even up to one year later (Schiller et al. 2010) though see (Kindt and Soeter 2013). Using a similar paradigm (Agren et al. 2012), it was additionally found that reactivating a fear memory shortly before extinction reduced amygdala activity during fear renewal on the following day and prevented fear reinstatement several days later, as measured by increased skin conductance responses (SCR). Thus, reactivating a memory before extinction training may be a noninvasive method for reducing the expression of fear memories in humans (Kindt and van Emmerik 2016; Beckers and Kindt 2017; 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 1985; Tulving and Murray 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 (Ritchey et al. 2013; Horner et al. 2015). 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 its administration (Kroes et al. 2014). 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. Other studies have investigated the impact of reactivating personal trauma-related memories. In Post-Traumatic Stress Disorder (PTSD) patients, propranolol was administered after specific intrusive negative memories were reactivated. In 3 out of 4 case studies, PTSD symptoms were significantly reduced after the intervention—in some cases, below the threshold of a PTSD diagnosis (Kindt and van Emmerik 2016), providing further evidence that reactivation and reconsolidation techniques can reduce even highly emotional, highly self-relevant autobiographical memories. There is also evidence that reactivation can weaken episodic memories if interfering information is introduced after reactivation. In one study, survivors of the Boston Marathon bombing recalled and described trauma-related memories, then read either a negative, neutral, or positive story afterward. One week later, the trauma memory was less accessible, as indicated by a lower word count for the second description, only for those who read the negative story after retrieval, perhaps because the negative story directly competed with the traumatic memory (Kredlow and Otto 2015). Thus, the details of previously-encoded episodic memories can be lost when their reactivation is followed by various interventions known to interfere with memory consolidation.

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 (Roediger et al. 1996; Pezdek et al. 2006; Desjardins and Scoboria 2007; Chan et al. 2009). 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. 2007, 2009, 2013; Hupbach et al. 2008; Gershman et al. 2013;). For example, after participants watched a movie about a fake terrorist attack, their memory for the event was either reactivated or not and misinformation was introduced. Interfering misinformation caused reduced recognition of items from the original memory only if reactivation occurred (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 (Yonelinas et al. 2019), 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 retrospective 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 ('online' reappraisal) or memory ('retrospective' reappraisal) by reinterpreting the experience (Ochsner et al. 2002, 2004; Wager et al. 2008), focusing on a positive outcome (Baker et al. 2017), or finding a 'silver lining' (Troy et al. 2010; Holland and Kensinger 2013a). 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. For example, in patients with claustrophobia, reappraisal after exposure to a threatening claustrophobic situation reduced fear to those stimuli more than exposure and subsequent safety-seeking behavior (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 retrospective 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 2013a) or aversive images (Holland and Kensinger 2013b) using self-generated memory titles. Self-reported negative affect during remembering was reduced by instructions to decrease emotion using retrospective reappraisal compared to instructions to maintain emotion. Importantly, one study also found that the effects of retrospective 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-min delay (Holland and Kensinger 2013a, b). However, it is not yet well understood what factors determine whether or not retrospective 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.

We propose that one way in which retrospective reappraisal differs from online reappraisal is in its reliance on memory reactivation and reconstruction processes to reduce the negative impact of emotional episodic memories (Fig. 1). During retrospective 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 (Nadel et al. 2012; Hupbach et al. 2013). 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 2013a, 2013b). 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.

While the relationship between memory reactivation and reappraisal success has not been extensively tested,

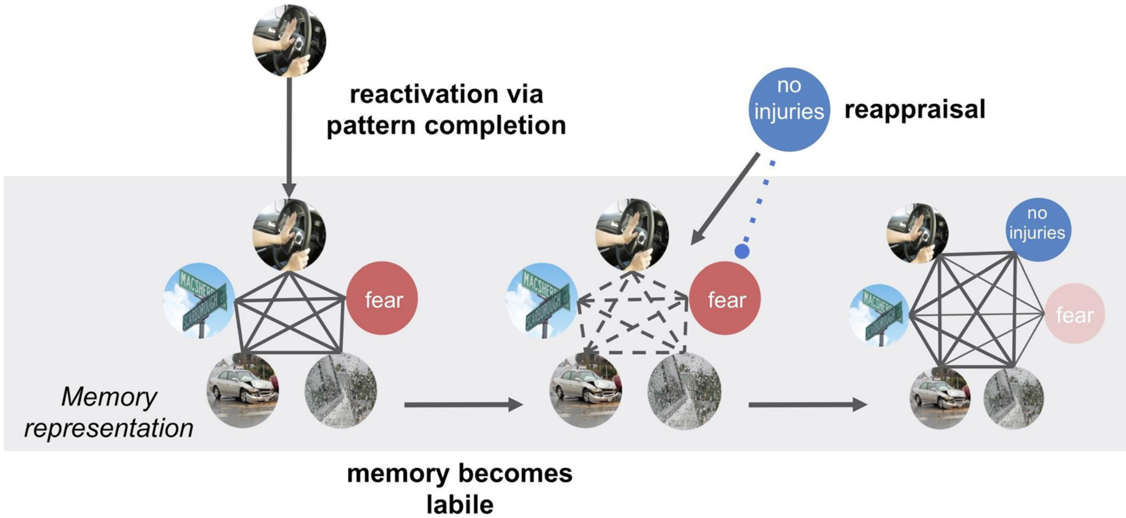

Fig. 1 Schematic of reappraisal as memory updating process. When a memory is cued, the memory representation is reactivated via pattern completion processes mediated by the hippocampus. The reactivated memory representation then becomes labile, allowing retrospective reappraisal to introduce new information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

established clinical treatments for affective disorders may support the mediating role of detailed memory reactivation in retrospective emotion regulation. The memory mechanisms discussed here may also be involved in reappraisal-like cognitive therapies that seek to explore prior life events, which have been used with success for years (Jones and Pulos 1993; Moertl et al. 2010). The importance of the strength of reactivation in retrospective emotion regulation is supported by evidence that emotional arousal when recounting trauma or anxiety-evoking situations in therapy is related to positive outcomes (Lane et al. 2015), suggesting that the emotional component of the memory must be reinstated in order to be modified. These ideas and findings are furthermore consistent with a long-standing framework for understanding how memory reactivation and exposure facilitate reductions in fear and anxiety: Emotional Processing Theory (Foa and Kozak 1986). This framework posits that in order for a fear memory to be therapeutically processed, information about the aversive stimulus, its interpretive meaning, and associated emotional and behavioral responses (Lang 1977, 1979) must be accessed before 'corrective' information may be incorporated into the representation, such as reevaluations of actual stimulus threat. Whereas Emotional Processing Theory has been applied primarily to explain changes in fear associations, here we elaborate on the role of memory reactivation in mediating cognitive reappraisals of complex episodic memories, which may further generalize to other kinds of negative emotions such as sadness, guilt, or anger (see Foa and Cahill 2001).

In contrast to the beneficial effects of reappraisal, there is some evidence that retrospective emotion regulation strategies that avoid detailed memory reactivation are relatively ineffective at 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 (Blalock and Joiner 2000; Holahan et al. 2005), 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. 2006, 2007), 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 2013a, 2013b). Additional work is needed to further investigate the influence of different retrospective regulation strategies 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 retrospective reappraisal, may be more effective at reducing negative affect and better at promoting adaptive learning compared to strategies that limit memory reactivation.

Concluding Remarks and Future Directions

Several lines of neuroscience research have offered insights into the mechanisms supporting memory-based strategies for reducing negative affect. Here, we review research suggesting that manipulations of memory reactivation influence the success of memory modification. We propose a framework that considers the role of memory reactivation in retrospective emotion regulation, whereby retrospective reappraisal leverages reconstructive memory processes to update and reduce the negative impact of emotional memories. A memory updating process that leaves details intact but decreases emotional impact during later remembering may be an effective and adaptive approach to coping with emotional memories. Though one may wish to simply forget an unpleasant event, emotional memories can play an important role in keeping us safe and allowing us to communicate important information to others. For example, if we are hurt by a certain person or in a particular location, it is adaptive to avoid that person or location in the future. 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 erased (Tulving 1974). Because retrospective 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 retrospective reappraisal maintains adaptive emotional memories even if the emotional impact is reduced.

Given that maladaptive memory processes such as rumination are associated with high negative affect (Harrington and Blankenship 2002) and the onset of depression (Nolen-Hoeksema et al. 2008), developing patterns of healthy habitual retrospective emotion regulation may intervene in the development of affective disorders. Interestingly, some studies have found benefits of training in cognitive reappraisal. In one such study, after watching a highly distressing film, participants who completed computerized reappraisal training interpreted ambiguous situations more positively, experienced a reduced number of unpleasant memory intrusions, and had reduced measures of posttraumatic stress over the following week (Woud et al. 2012). Because the training occurred after rather than before the film, these effects may reflect the use of retrospective reappraisal to cope with related unpleasant memories. In another study, laboratory-based training in reappraisal not only reduced negative affect while viewing unpleasant images two weeks later, but also increased habitual and automatic use of reappraisal in everyday life (Christou-Champi et al. 2015). Though these studies did not assess retrospective reappraisal per se, these findings suggest that reappraisal training may be an inexpensive, accessible, and effective intervention in the development of affective disorders (Woud et al. 2012; Denny and Ochsner 2014; Keng et al. 2016). If the degree of episodic memory reactivation is crucial for successful retrospective reappraisal, training programs may benefit from emphasizing memory retrieval as a key part of the process.

The research discussed in the current review suggests that retrospective 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, arousal), further work is necessary to establish the long-term efficacy of different applications of retrospective reappraisal. In evaluating the robustness of this effect, future work might consider questions such as whether retrospective reappraisal 'permanently' reduces negative affect during remembering, or if the persistence of emotional memories causes negative emotionality to eventually return. Furthermore, questions regarding the memory mechanisms underlying retrospective regulation remain. For example, is there a simple relationship between reactivation strength and reappraisal success, such that the stronger the reactivation, the more effective the memory modification? Or does very strong reactivation make retrospective emotion regulation prohibitively difficult (Ritvo et al. 2019)? It is also unclear whether other retrospective emotion regulation strategies, such as mindfulness and distancing, can leverage the reactivation of specific memories. Answering questions such as these may help to inform more targeted interventions and treatments for affective disorders.

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Compliance with Ethical Standards

Conflict of Interest Rosalie Samide and Maureen Ritchey declare that they have no conflicts ofinterest.

Ethical Approval This article does not contain any studies with human participants performed by any of the authors.

Informed Consent For this type of study formal consent is not required.

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