



The retrograde effects of negative emotion on memory for conceptually related events: a registered report

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ABSTRACT

Emotional events are often remembered better than neutral ones; however, emotion can also spill over and affect our memory for neutral experiences that precede an emotional event. Theories suggest that emotion can retroactively enhance memory for preceding neutral events that are considered high-priority while impairing memory for events deemed low-priority. However, the impact of conceptual relationships (i.e., semantic connections) between preceding neutral information and emotional events on memory for the preceding information has received little attention. This study investigated the influence of conceptual relatedness on the retroactive effects of emotion on memory. Participants sequentially encoded pairs of images that were high or low in conceptual relatedness, each comprising a neutral object followed by either a negative or neutral image. Participants returned the next day for a recognition memory assessment. The results indicated an interactive effect of emotion and conceptual relatedness on memory: In a “discovery” sample, memory was poorer for images preceding conceptually unrelated negative (vs. neutral) images, while the opposite pattern was seen for conceptually related images. In a “replication” sample, these effects were partially replicated, with the former impairment effect statistically observed but not the latter augmentation effect. Hence, conceptual relatedness affects how negative emotion influences memory.

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Introduction

It is well-established that emotion enhances some aspects of memory (Adelman & Estes, 2013; Christianson & Loftus, 1991; Kensinger et al., 2007; McGaugh, 2004; Reisberg & Heuer, 2004; see LaBar & Cabeza, 2006; Yonelinas & Ritchey, 2015 for a review). For example, if you were walking in the forest and you encountered a snake, you are much more likely to remember this encounter relative to more mundane events (such as encountering a squirrel). The memory enhancement that has been observed for emotional events has been attributed to a multitude of processes at every stage of memory including encoding, consolidation, and retrieval (see Levine & Edelman, 2009).

However, emotion does not enhance all aspects of memory. Some studies have found that neutral information presented in close spatial or temporal proximity to an emotional event is less likely to be remembered, in part due to the attentional demands of emotional stimuli not leaving adequate cognitive resources to process the surrounding neutral information. For example, if an image of a snake is presented on a neutral background, individuals are likely to remember the emotionally salient snake, whereas memory for background details is likely to be impaired (often referred to as a central-peripheral trade-off; Brown, 2003; Burke et al., 1992; Kensinger et al., 2005, 2007; Mather & Sutherland, 2011; Pickel et al., 2003). Memory for peripheral neutral details, however, is not always impaired;

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alternatively, memory for these details can be enhanced if those details are considered *goal-relevant*. That is, neutral information relevant to one's goals at the time of encoding can experience a memory enhancement (Brierley et al., 2007; Burke et al., 1992; Christianson & Loftus, 1991; Mather & Sutherland, 2011; also see Levine & Edelman, 2009). Mechanistically, goal-relevant stimuli, regardless of valence, can result in increased amygdala activation (Cunningham et al., 2008) and noradrenergic (NE) activity (Clewett et al., 2017), which can bolster such stimuli in memory.

These complex effects of emotion on memory for neutral details are not just present for *co-occurring* information, they can also impact neutral details that *precede* an emotional event. As detailed below, such retrospective mnemonic effects are the focus of this paper.¹ Indeed, real-world experiences unfold in a context, with a continuous stream of events occurring before, during, and after an emotional event. In this temporal context, emotion can have a *spillage effect*, whereby it influences memory for information that directly precedes the emotional event. To explore this phenomenon, researchers have attempted to mirror how real-world events unfold in the lab by presenting items (e.g. pictures or words) sequentially, to investigate how emotion can influence our memory for neutral stimuli preceding an emotional event (see Schlüter et al., 2019, for review).

These studies have, however, yielded seemingly conflicting findings. Whereas some earlier work has shown that emotion – particularly negative emotion – retroactively enhances memory (Anderson et al., 2006; Dunsmoor et al., 2015; Forester et al., 2020; Knight & Mather, 2009; Liu et al., 2008; Nielson et al., 2005; Nielson & Powless, 2007; Sakaki et al., 2014), other studies show that negative emotion impairs² or has no effect on memory (Hurlemann et al., 2005; Miu et al., 2005; Strange et al., 2003, 2010; Tulving, 1969; Wang & Ren, 2017; see Schlüter et al., 2019). Although there have been theories proposed to aid our understanding of these conflicting results (detailed below), the boundary conditions for this effect require further investigation.

Impairments for neutral stimuli preceding an emotional event have been observed in a variety of studies using both a block paradigm (where a series of to-be-tested stimuli is encoded followed by an emotional event; Wang & Ren, 2017) and an oddball paradigm (i.e. a detailed image of a negative, positive or neutral scene amongst simplistic images of objects;

Hurlemann et al., 2005; Knight & Mather, 2009; Strange et al., 2003, 2010; also see Tulving, 1969). For example, Hurlemann et al. (2005) had participants sequentially encode sets of eight images with one of the images being an *oddball*. After each set, participants recalled as many images as they could remember, and it was observed that participants were less likely to recall images that had preceded a negative oddball. Some researchers have attributed these post-encoding impairments to the close temporal proximity of the emotional induction to preceding information (Tulving, 1969; Wang & Ren, 2017), wherein the preceding stimuli may still be undergoing the process of early consolidation when it is sharply interrupted by the arousal induced by the emotional event. More specifically, NE-induced activation of the amygdala may lead to a diversion of cognitive resources to process the emotional event (Hurlemann et al., 2005; Miu et al., 2005; Strange et al., 2003). Possible support for this mechanism was observed in both Hurlemann et al. (2005) and Strange et al. (2003), wherein the authors found that they could block or exacerbate these impairment effects by manipulating arousal responses through central NE (via adrenoceptor antagonists and agonists).

By contrast, other studies have shown the opposite pattern, namely one of emotional retroactive memory enhancement. In a seminal study by Anderson et al. (2006), participants saw sequentially presented pairs of images, where the latter image was either negative or neutral, and assessed recognition memory for the preceding images one week later. The authors found a retrograde memory enhancement for neutral images that preceded negative images when the emotional images induced high levels of emotional arousal. The authors suggested that this enhancement was the result of arousal induced-amygdala activation. Thus, an arousal mechanism – thought to contribute to emotional retroactive memory impairment – has also been postulated as a mechanism for retroactive memory enhancement.

In an effort to reconcile these seemingly conflicting findings, Mather and colleagues have proposed that enhancements are likely due to the *priority* of preceding information, which can be dictated by the bottom-up salience or goal-relevance of the preceding information. For example, Knight and Mather (2009) suggest that the retrospective enhancement effect occurs only when the preceding information is retroactively deemed *goal-relevant*. In support of

this idea, a study by Sakaki et al. (2014) used an oddball paradigm where they manipulated the goal-relevance of items preceding an emotional or neutral oddball by telling participants to focus on remembering specific images. They observed that when participants were told to prioritise images preceding a neutral or emotional oddball (high-priority condition), there was a memory enhancement for images preceding emotional oddballs relative to those preceding neutral oddballs. Alternatively, when participants were told to prioritise another image in the set (low-priority condition), they observed an impairment for images preceding emotional oddballs. This study illustrated that emotion has the potential to both retroactively impair and enhance memory depending on the priority assigned to the preceding stimuli. As an interpretation of Anderson et al. (2006), Mather and colleagues suggest the first item in each pair in their paradigm is deemed high-priority, possibly due to the exclusivity of the pairwise presentation, and the memory-orienting question presented alongside the preceding item (i.e. *Will you remember this item?*). These design features may bolster priority, and could in turn account for the observed retroactive memory enhancement (see Knight & Mather, 2009; Mather & Sutherland, 2011), consistent with the arousal-biased-competition model (see Mather & Sutherland, 2011).

These studies – e.g. Knight & Mather, 2009; Sakaki et al., 2014 – have elucidated the mechanisms that underlie the mixed findings on the retroactive effects of emotion on memory, emphasising the influence of priority. This work opens the door to build on this research and investigate further how we can modulate the priority of preceding information, thus influencing how it is remembered. We and others propose that the conceptual relationship between preceding information and an emotional event itself can modulate the amount of priority (goal-relevance) adopted by the preceding item (also see Schlüter et al., 2019). When real-life experiences unfold, there is a continuous flow of events that can allow for the perception of causal links between stimuli (Reisberg & Heuer, 2004). In other words, preceding stimuli become goal-relevant because they adopt predictive utility, in that they become a useful indicator of threat in future situations and are thus prioritised in memory (Palombo & Cocquyt, 2020). The ability to create these predictive associations is an imperative component to avoiding

negative/aversive stimuli in future situations. For example, on your walk through the forest where you encountered the snake, you may remember stimuli that preceded it differently depending on their perceived relevance to the snake. Although some prior research suggests that emotion may facilitate associative memory for objects and background when they are conceptually congruent (Madan et al., 2020), how these conceptual relationships influence the retroactive effects of emotion on memory is less clear (for related ideas, see Dunsmoor et al., 2015; Madan, 2024). Note that such a scenario differs from the work by Mather and colleagues in that the priority of preceding stimulus is determined by virtue of its conceptual link with the subsequent event. Although there is little work on this topic, a highly relevant study by Smith and Beversdorf (2008) investigated the effects of semantic relatedness via a verbal oddball paradigm where they manipulated both the valence and semantic relationship of the word preceding the oddball. In this study, relevant analyses showed enhanced immediate free recall for words that were semantically related to a subsequent oddball word, a finding that was stronger for negative versus neutral oddballs. This finding supports the importance of conceptual relatedness with respect to emotional retroactive influences on memory.

The goal of the current study is to further shed light on how conceptual relatedness and emotion interact to influence memory for preceding information. Given prior findings, particularly the important work by Smith and Beversdorf (2008), we hypothesised that emotion (in this case, negative emotion; the focus of our study) would more strongly *enhance* memory for neutral images preceding highly conceptually related images (high predictive utility), producing an emotion-by-semantic-relatedness interaction. Such a finding would provide conceptual replication of Smith and Beversdorf (2008) and build on the findings of Anderson et al. (2006) by manipulating priority via conceptual relatedness as opposed to task instructions (with regard to the test items).

In considering the nature of the proposed interaction further, a second hypothesis, namely that emotion could *impair* memory for neutral images preceding images low in conceptual relatedness (low predictive utility), was more tentative. On the one hand, under some circumstances, low predictive utility can lead to retroactive impairments in memory via emotion as emotion suppresses non-salient representations. Under conditions of low

predictive utility for $n-1$ items, it is possible that a highly arousing n item occupies priority space. Yet, the hypothesised impairment was not observed in the study by Smith and Beversdorf (2008).³ Hence, an alternative hypothesis is that emotion would have no retroactive effect on memory in the unrelated condition. In both cases, the predicted effect involves a significant emotion \times conceptual-relatedness interaction.

Method

Participants

This study was approved by the Behavioural Ethics Board at the University of British Columbia (UBC) and any amendments needed in association with this Registered Report were submitted and approved before the study began. All participants were fluent in English and between 18 and 35 years old. Participants were recruited through Prolific for monetary compensation and tested online. Participants were randomly assigned (via a Qualtrics algorithm) to one of two experimental groups: group A (related) or group B (unrelated). A mixed design was used in this study to avoid introducing confounds into the experiment, as unpacked below. To determine the final sample size, a power analysis was conducted via *G*Power*. Assuming a small-to-medium effect size ($\eta_p^2 = 0.025$) and 95% power, a minimum N of 130 (65 participants per group) is needed to observe a statistically significant between-within interaction. Note that recruitment was open to all gender identities, and we effectively recruited a balance of individuals who identify as women and men (we aimed for no greater than a 45% vs. 55% difference).

Participants were excluded if they performed below chance on the recognition-memory task (collapsed across conditions) described below, evidenced by a d' at or below 0, in at least one of the two blocks. Participants were also excluded if they failed both attention check questions (the study contained two attention check questions total⁴) or if they provided the same or no response for 24 or more consecutive trials during the retrieval task.⁵ We continued to sample until we reached the noted final sample in each group. A full replication sample, using the same sampling procedures noted above, was collected to ensure robustness of the findings. To keep the samples distinct, we refer to the two samples as “discovery” and “replication”.

In the discovery sample, of the 140 participants who completed the study, 9 were excluded for having d' scores at or below 0, and an additional 1 was excluded for missing or repeated responses to consecutive trials. The final sample consisted of 130 participants, 65 of which were in group A ($M_{\text{age}} = 26.60$, $SD_{\text{age}} = 4.42$; 1 non-binary, 31 women, 33 men) and 65 in group B ($M_{\text{age}} = 27.91$, $SD_{\text{age}} = 4.67$; 1 non-binary, 1 two-spirit, 1 undisclosed, 31 women, 31 men).

In the replication sample, of the 142 participants that completed the study, 8 were excluded for having d' scores at or below 0, and an additional 4 were excluded for missing or repeated responses to consecutive trials. The final sample consisted of 130 participants, 65 of which were in group A ($M_{\text{age}} = 27.49$, $SD_{\text{age}} = 4.51$; 32 women, 33 men) and 65 in group B ($M_{\text{age}} = 27.82$, $SD_{\text{age}} = 4.43$; 1 non-binary, 1 genderqueer, 31 women, 32 men).

Materials and stimuli

This overall procedure was administered online through Qualtrics (<https://www.qualtrics.com>), which hosted the consent form, as well as a demographics and health screen⁶ that were used to characterise our sample in terms of gender, age, and education. Pavlovia (<https://pavlovia.org>) hosted the memory task. The task was programmed using the latest version of PsychoPy (Pierce et al., 2019) and then uploaded onto Pavlovia.

To give an overview of the design, the study employed a mixed design. The *between*-groups component involved two experimental groups, group A and group B, who encoded sequential stimuli pairs that were either related or unrelated, respectively. The *within*-groups component involves each group encoding stimuli that were negative and neutral (Figure 1). That is, in our 2×2 design, both the conceptual relationship and valence were manipulated.

For the stimuli, images were chosen from the Nencki Affective Picture System database (NAPS; with permission; Marchewka et al., 2014) hereafter referred to as *modulator* images (shown in Figure 1; also see Figure 2), as these images are those that potentially modulate the fate of the preceding images. Valence of the modulator images (negative or neutral) were determined through NAPS normative ratings of valence (from 1 = *very negative* to 9 = *very positive*, with 5 = *neutral*) and arousal (from 1 = *relaxed* to 9 = *aroused*, with 5 = *neutral*; Marchewka

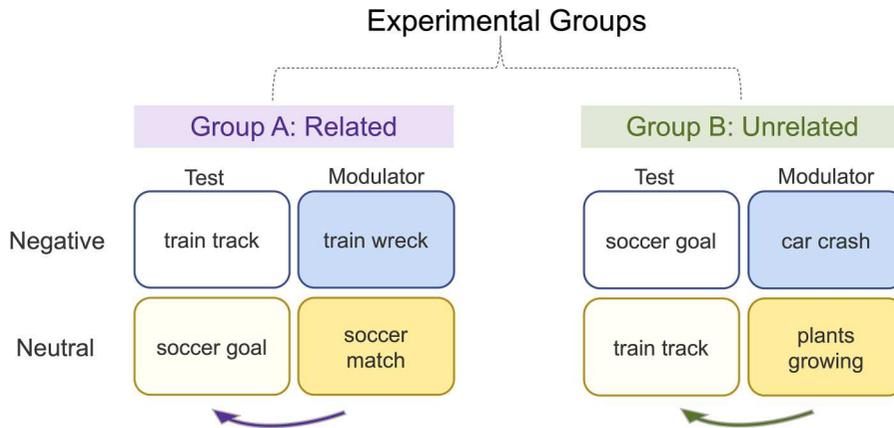


Figure 1. Overview of 2×2 design. This schematic depicts the breakdown of the proposed mixed-subjects design. Relatedness is the between-subject factor and valence is the within-subject factor. For the “modulator” images (see Main Text), the fill colour reflects the valence of that image, blue for negative, yellow for neutral. For the “test” images the border colour reflects the valence of its co-pair.

et al., 2014). For our stimuli selection, we set out to have negative images with valence scores between 1 and 4 and arousal scores between 6 and 9, and neutral images with valence scores between 5 and 7 and arousal scores less than 5. In our Stage 1 Registered Report, we stated that the ranges would be mildly adjusted (i.e. by 0.5 of a point) to ensure a fully balanced stimuli set. As shown in Tables S1–S2, we achieved our goal, with no adjustments needed.

A different set of NAPS images were used in groups A and B to allow for the same test items to be used in both groups (see below). There were 24 images included per condition in each group. An additional 16 images were used in each condition to serve as foils (i.e. new items) in the memory task, as detailed below. We ensured strict matching of stimuli in the two groups (group A and B) in terms of valence and arousal.

To ensure there were no differences in the visual properties of modulator items assigned to each valence (negative vs. neutral) by relatedness (unrelated vs. related) condition, independent t-tests were conducted, comparing visual properties between and across NAPS images in each group (with a minimum $p = .20$ for condition comparisons). That is, images selected in each condition were highly matched on visual features, including luminance, contrast, entropy, and R,G,B content, as such factors can influence the memorability of images. We also statistically balanced the number of stimuli from different stimulus groups pertaining to faces, landscapes, animals etc., which were provided by the NAPS database.

Images of objects were used for the stimuli that precede modulators, hereafter referred to as the *test* images, and were selected from the Bank of Standardized Stimuli database (BOSS; Brodeur et al., 2014). Additional test images were chosen from the internet to supplement this set. To ensure our test images in the related condition are conceptually related to their respective modulators, and that those in our unrelated condition are conceptually unrelated, a norming study was conducted first to choose such stimulus pairs (Figure 3); the details of the norming can be found in the Supplementary Information. Importantly, the same test images were used in Groups A and B but differed in which experimental condition they belonged to. Indeed, a cross-over design was chosen, wherein each of the test images was paired with a related modulator image in one group and an unrelated modulator image in the other (i.e. a test image paired with a negative-related modulator image in group A would be paired with a neutral-unrelated modulator image in group B). This design was chosen to ensure that every test item in the set is represented in every experimental condition.⁷ The critical properties (and associated statistics) for the selected stimuli are demonstrated in Supplementary Information and Tables S1–S5.

Procedure

The memory paradigm was loosely modelled after Anderson et al. (2006) and involves participants sequentially viewing pairs of images. The *encoding*

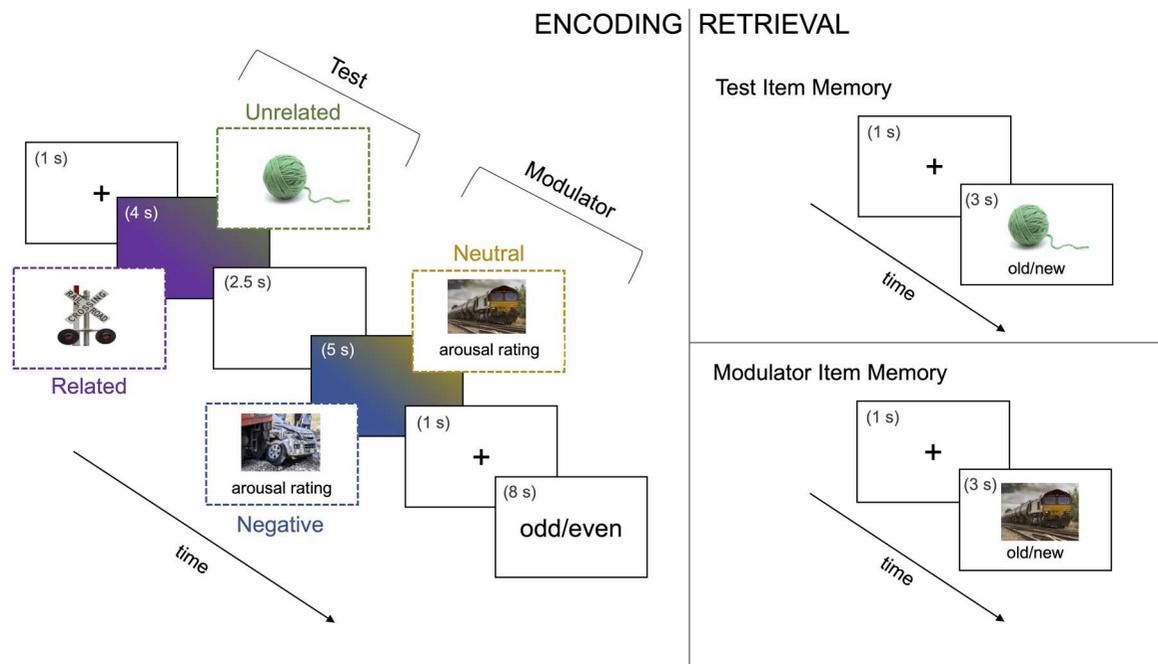


Figure 2. Experiment task procedure. Illustration of the encoding and recognition (“retrieval”) tasks. Substitute pictures from the internet are shown for the BOSS and NAPS images to protect the usage of the BOSS and NAPS databases. Images used in these figures were purchased from *shutterstock.com* and used with permission.

phase included two different types of events: *modulator* events, wherein participants are shown images that are emotional or neutral, and *test* events, wherein participants are shown neutral images prior

to the modulator. The methods for group A and B were identical except for the nature of the relationship between the test and modulator items. Notably, the encoding phase employed an incidental

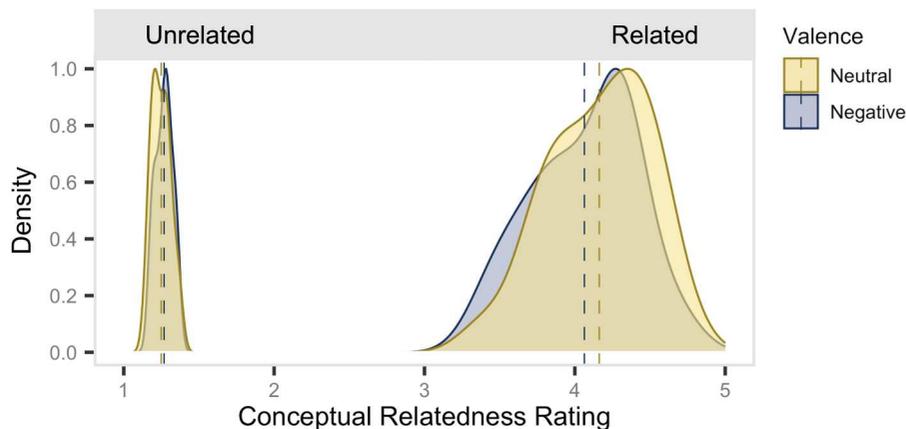


Figure 3. Conceptual relatedness ratings for NAPS-object image pairs (determined through norming, see Supplemental Information). Density plots are depicted for display purposes and density is scaled to a maximum of 1 for each condition for ease of visualisation. Dashed vertical lines reflect the mean relatedness rating for the corresponding condition. Although there is more spread in the related condition than the unrelated condition, critically, the figure shows that the relatedness/unrelatedness distributions are well matched for negative and neutral images and the magnitude of difference between related and unrelated is well matched across the negative and neutral conditions. Also see Supplemental Information.

encoding approach in which participants were not informed that their memory would later be tested.

Each trial of the encoding phase started with a test event, followed by a modulator event, and ended with a filler task (see Figure 2 for an example trial and trial duration). The test event consisted of an image of a neutral object (BOSS/internet) presented for 4 s, which was either related or unrelated to the subsequent modulator event.⁸

Following an interstimulus interval (ISI; 2.5 s), participants then viewed the modulator event for 5 s, which consists of either a negative or neutral NAPS image. Akin to Anderson et al. (2006), participants were asked to indicate via their mouse how emotionally aroused the image makes them feel on a Likert scale from 1 “Relaxed” to 5 “Emotionally Aroused”. Following another ISI (1 s), they then completed an 8-second filler task where they were asked to indicate whether a number on the screen is odd or even via keyboard response. This filler task was designed to limit emotional carry-over between trials. This was followed by a 1-second inter-trial interval (ITI). Each trial lasted 21.5 s (including ITI).

The memory *retrieval phase* that followed encoding between 20 and 28 hours later (average delay in hours, discovery: $M = 23.82$, $SD = 1.42$, replication: $M = 23.51$, $SD = 1.43$) consisted of a recognition memory task. We opted to use a delayed recognition memory task as prior work has shown stronger effects of emotion on memory after a delay due to the slower forgetting of emotional versus neutral content (Yonelinas & Ritchey, 2015). The precise delay was determined through piloting. Although some of our prior work using a superficially similar emotional memory paradigm (online testing) showed ceiling effects in ~35% of participants with only a 24-hour delay (Stewardson et al., 2022), we opted for 24-hour delay to limit participant attrition and due to minimal ceiling effects observed during piloting. Indeed in our final dataset, we only observed ceiling performance (collapsed across conditions) in 1% of participants when considering ceiling as no incorrect trials. If we use a more liberal criterion (i.e. participants who only had 4 or less incorrect trials), that value goes up to 13%.

Participants completed two blocks of the recognition task, the first of which assessed their memory for test images and the second assessed their memory for modulator images. In each block, participants viewed a series of images, some of which were “old” (seen at encoding) and some of which were “new” (not seen at encoding; foils), presented in a

randomised order. Participants viewed each image for a minimum of 500 milliseconds and were given up to 3 s to indicate via keyboard response whether they believed the image on the screen was “old” or “new” (while the image was still presented), pressing Q for “old” and W for “new.” Each trial was followed by a 1-second ITI. See Supplementary Information for stimulus characteristics for old versus new stimuli.

For both encoding and retrieval, participants received three practice trials.

Analyses

Data were processed and analysed in R, version 3.6.1 (R Core Team, 2019) using core packages (e.g. *base*, *stats*), as well as *rstatix*, version 0.6.0 (Kassambara, 2020). Plots were produced via the package *ggplot2*, version 3.3.5 (Wickham, 2016). The data can be accessed via: <https://osf.io/92nqr/>.

To measure memory performance on the recognition task, participants’ responses were categorised as *hits* (correctly identified an old image as “old”), *misses* (incorrectly identified an old image as “new”), *correct rejections* (correctly identified a new image as “new”) and *false alarms* (incorrectly identified a new image as “old”). In this study we used signal-detection theory (Wixted, 2007) to derive a sensitivity index, d' by taking the z transform of hits minus the z transform of false alarms (i.e. $d' = z(H) - z(F)$), with a higher d' value indicating greater sensitivity. To correct for instances where a participant obtains a hit rate of 1 or a false alarm rate of 0, the following corrections were applied to avoid infinite d' values (Macmillan & Kaplan, 1985). Hit rates of 1 were revalued as $1 - (1 / 2N_H)$ where N_H is the total number of potential hits, and false alarm rates of 0 were recalculated as $1 / (2N_{FA})$ where N_{FA} is the total number of potential false alarms.

Two separate 2×2 (valence-by-relatedness) mixed ANOVAs were conducted to examine the separate and combined effects of valence and relatedness on memory performance denoted by d' : one on the test images and one on the modulator images. In the event of a statistically significant interaction ($p < .05$) we conducted post-hoc t-tests to determine the nature of this interaction. This would consist of two pairwise comparisons, to explore the effects of valence within each relatedness condition, and two independent-samples t-tests, to explore the effects of relatedness within each valence condition. Statistical significance was considered as $p < .0125$ as per

Bonferroni correction for four comparisons of interest, namely negative vs. neutral in each relatedness condition and related vs. unrelated in each valence condition. Data were assessed for normality to ensure the assumptions of this model are met, specifically through the use of the Shapiro-Wilks test and visual inspection of histograms and QQ plots. In line with prior studies using a similar paradigm and the sample size, the data approximated a normal distribution.

Results

Modulator images

For assessment of d' scores for modulators, in the discovery sample, the mixed-effects ANOVA showed the expected significant main effect of valence ($F(1,128) = 59.26$, $p < .001$, $\eta_p^2 = .32$), wherein negative modulators were remembered better than neutral modulators (i.e. the prerequisite emotional memory enhancement). By contrast, we observed no main effect of relatedness ($F(1,128) = 0.24$, $p = .63$, $\eta_p^2 = .002$) as well as no significant valence by relatedness interaction ($F(1,128) = 1.68$, $p = .20$, $\eta_p^2 = .01$). These results replicated in the replication sample: The main effect of valence was significant ($F(1,128) = 55.21$, $p < .001$, $\eta_p^2 = .30$) where negative modulators were remembered better than neutral modulators irrespective of whether they were preceded by a conceptually related stimulus. See [Figure 4](#); see [Table 1](#) for descriptive statistics.

Test images

For assessment of d' for test images, in the discovery sample, the mixed-effects ANOVA yielded no significant main effect of valence ($F(1,128) = 0.04$, $p = .84$, $\eta_p^2 < .001$) or relatedness ($F(1,128) = 0.99$, $p = .32$, $\eta_p^2 = .01$). Critically, the valence by relatedness interaction did yield a significant effect ($F(1,128) = 23.41$, $p < .001$, $\eta_p^2 = .16$). In the replication sample, we observed a similar, albeit not identical pattern of results. Specifically, we replicated the critical valence by relatedness interaction ($F(1,128) = 16.99$, $p < .001$, $\eta_p^2 = .12$). As in our discovery sample, we did not observe a significant main effect of relatedness ($F(1,128) = 3.38$, $p = .07$, $\eta_p^2 = .03$), yet, unlike the discovery sample, the replication sample produced a significant main effect of valence ($F(1,128) = 5.60$, $p = .02$, $\eta_p^2 = .04$). See [Figure 5](#); see [Table 1](#) for descriptive statistics.

Although the hypothesised valence by conceptual relatedness interaction emerged in both samples, the nature of the interaction differed across the two cohorts and – to some extent – from our hypothesis, per post-hoc analyses. As noted earlier, significance for post-hoc tests was considered as $p < .0125$, per Bonferroni correction for 4 comparisons of interest, namely negative vs. neutral in each relatedness condition (paired t-tests) and related vs. unrelated in each valence condition (independent samples t-tests). All such comparisons were necessary to fully understand the nature of our effects. All t values reported below are unsigned for simplicity.

In the discovery sample, the post-hoc analyses determined that, as hypothesised, in the related condition, test images preceding negative modulators were remembered significantly better than those preceding neutral modulators ($t(64) = 3.48$, $p < .001$, $d = 0.43$). The inverse effect was observed in the unrelated condition wherein test images preceding negative modulators were remembered significantly worse than those preceding neutral modulators ($t(64) = 3.36$, $p = .001$, $d = 0.42$). Hence, we observed a cross-over interaction with similar effect sizes for both comparisons. For relatedness comparisons, there were no significant differences between unrelated and related test images preceding neutral modulators ($t(128) = 0.62$, $p = .54$, $d = 0.11$). Yet, test images preceding negative modulators were remembered better when related versus unrelated ($t(128) = 2.42$, $p = .017$, $d = 0.42$). While this effect did not meet our Bonferroni correction ($p < .0125$), and hence is considered marginally significant, we note that the effect size is on par with those observed in the aforementioned significant results.

In the replication sample, the pattern was such that, contrary to our hypothesis and the discovery sample, in the related condition, test images preceding negative modulators were not remembered significantly better than those preceding neutral modulators ($t(64) = 1.27$, $p = .21$, $d = 0.16$), although the numerical pattern was the same (but the effect size is much smaller). Akin to the discovery sample however, the inverse effect was observed in the unrelated condition wherein test images preceding negative modulators were remembered significantly worse than those preceding neutral modulators ($t(64) = 4.48$, $p < .001$, $d = 0.56$). For relatedness comparisons, the pattern was similar to the discovery sample: There were no significant differences between unrelated and related test images in the neutral condition (t

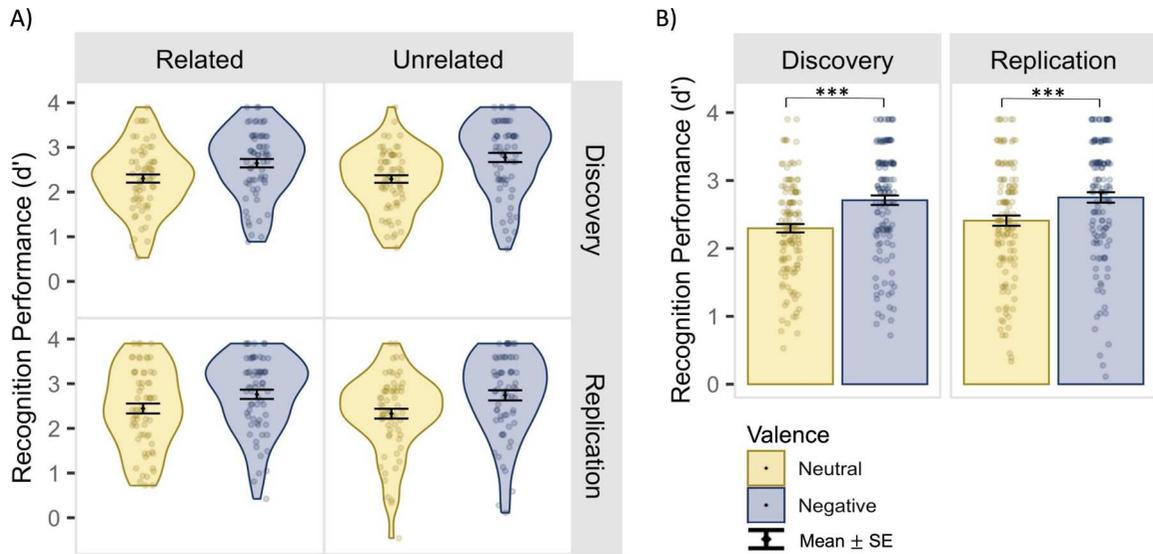


Figure 4. Recognition performance for modulator images via d' scores. (A) performance for each relatedness by valence condition in the discovery (top) and replication (bottom) samples. (B) illustration of the significant main effects of valence in each sample. *** $p < .001$. Maximum d' score = 3.90.

(128) = 0.53, $p = .60$, $d = 0.09$), yet we did observe a significant effect in the negative condition, wherein related test images preceding negative modulators were remembered better than those which were unrelated ($t(128) = 2.90$, $p = .004$, $d = 0.51$). Hence across cohorts, the consistent, robust finding in the data was that when test items were unrelated to their modulators, negative emotion had an impairing effect on memory.

Exploratory [combined-samples] analyses (ECSA)⁹

Although the analyses of the two samples yielded many converging results, some patterns were unique to each sample. To explore whether any meaningful patterns were underpowered in the individual samples, exploratory analyses were conducted with participants collapsed across the discovery and replication cohorts ($N = 260$), an approach which has been used in prior work (e.g. de Montpellier & Talmi, 2023). Consistent with the individual samples, for the modulators there was a main effect of valence ($F(1,258) = 115.03$, $p < .001$, $\eta_p^2 = .31$) and no significant main effect of relatedness ($F(1,258) = .003$, $p = .96$, $\eta_p^2 < .001$) or interaction ($F(1,258) = 2.55$, $p = .11$, $\eta_p^2 = .01$).

For the test images, consistent with the individual samples, we observed the critical significant relatedness by valence interaction ($F(1,258) = 39.97$, $p < .001$, $\eta_p^2 = .13$). The main effect of valence was not significant ($F(1,258) = 2.25$, $p = .13$, $\eta_p^2 = .01$), nor was the effect of relatedness, albeit a marginal trend was evident ($F(1,258) = 4.01$, $p = .05$, $\eta_p^2 = .02$).

Post-hoc analyses decomposing the interaction showed that test images preceding negative modulators were remembered significantly better than those preceding neutral modulators in the related condition ($t(129) = 3.39$, $p < .001$, $d = 0.30$). Recall that this effect was numerically observed in both individual samples but only significant in the discovery sample. In the combined sample, the effect size is slightly smaller than that of the discovery sample, as one would expect given the results of the replication sample. Per both individual samples, the inverse effect in the unrelated condition was also observed, wherein test images preceding negative modulators were remembered significantly worse than those preceding neutral modulators ($t(129) = 5.56$, $p < .001$, $d = 0.49$). Moreover, for the relatedness comparisons, whereas there were no significant differences between unrelated and related test images in the neutral condition ($t(258) = 0.06$, $p = .96$, $d = 0.01$), in the negative condition, related test images preceding modulators were remembered significantly better than those

Table 1. Recognition performance by condition via d' scores.

Image	Relatedness	Valence	Sample					
			Discovery N = 130		Replication N = 130		Combined N = 260	
			Mean	SD	Mean	SD	Mean	SD
Modulator	Unrelated	Neutral	2.29	0.68	2.33	0.88	2.31	0.78
		Negative	2.77	0.83	2.74	0.92	2.76	0.87
	Related	Neutral	2.30	0.74	2.44	0.90	2.37	0.82
		Negative	2.65	0.76	2.76	0.83	2.70	0.80
Test	Unrelated	Neutral	1.59	0.65	1.73	0.65	1.66	0.65
		Negative	1.41	0.67	1.49	0.78	1.45	0.73
	Related	Neutral	1.51	0.68	1.79	0.70	1.65	0.70
		Negative	1.71	0.72	1.86	0.67	1.78	0.70

Note: Means and standard deviations of d' scores, by sample, in each valence by relatedness condition for modulators and test images.

which were unrelated ($t(258) = 3.77, p < .001, d = 0.47$) – an effect that did not reach the multiple comparison correction threshold in the discovery sample, but was significant in the replication sample. The means and standard deviations for the discovery, replication, and ECSA samples are presented in Table 1 for summary purposes.

Discussion

We demonstrate that memory for a stimulus preceding an emotional item (i.e. a “modulator”) is dependent on the *conceptual relationship* between them (i.e. an interaction effect). This proposed effect is substantiated by the observed interactions for “test”

items in both of our independent samples. Despite slight variations in the statistical outcomes between samples, the trends and directional nature of this interaction remain consistent and emerged as robust in our exploratory combined-samples analyses (ECSA).

Our most robust effect, which emerged in both of our discovery and replication samples, was within the unrelated condition; as such, we begin our discussion by focusing on this finding. Note that the design of the unrelated condition here was more similar to many prior studies, wherein relationships between stimuli are not directly manipulated – although, in our study, deliberate efforts were made to ensure the stimulus pairs were *unrelated* (determined via

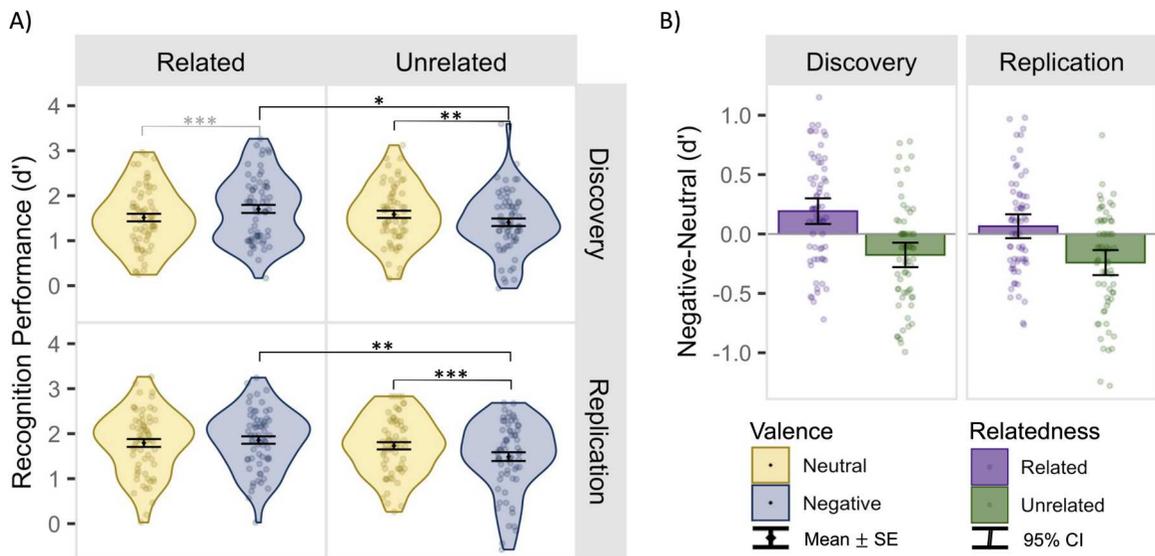


Figure 5. Recognition performance for test images via d' scores. (A) performance for each relatedness by valence condition in the discovery (top) and replication (bottom) samples. (B) difference d' scores (negative-neutral) in each relatedness group for each cohort. Only significant a priori pairwise comparisons are indicated. Uncorrected $*p < .05$, $**p < .01$, $***p < .001$. Maximum d' score = 3.89.

norming) to attenuate the priority of the test item in this condition. Here, we observed poorer memory for images preceding a negative stimulus compared to those preceding a neutral one. Such a finding is consistent with studies which have also observed a retrograde memory impairment (Hurlemann et al., 2005; Knight & Mather, 2009; Strange et al., 2003, 2010; see Schlüter et al., 2019), although Smith and Beversdorf (2008) did not observe such an effect (see Introduction for possible methodological reasons). As noted in the Introduction, a possible mechanism for the effect observed here is that early consolidation processes are disrupted when the preceding test item is of low priority relative to the subsequent emotional modulator, which usurps processing demands to occupy priority space (Tulving, 1969; Wang & Ren, 2017). Extending beyond this interpretation, prior research also suggests that emotional stimuli can effectively “flush” out the contents of working memory, eliminating or attenuating information that might otherwise be retained through working memory maintenance (Dolcos & McCarthy, 2006). It is possible that these mechanisms are not mutually exclusive, but our study is not designed to adjudicate between them.

The retroactive effects of emotion proved more complicated when there was a conceptual relationship between the preceding stimulus and the emotional event. That is, the effects that we observed in the related condition alone warrant a more nuanced interpretation due to differences in magnitude across our discovery and replication samples. Specifically, in the related condition, we noted a statistically significant, hypothesised enhancement in memory for images preceding a negative stimulus compared to those preceding a neutral one in our discovery sample and ECSA (conceptually replicating Smith & Beversdorf, 2008), but this statistically significant effect was not observed in our replication sample, which also yielded a much smaller effect. The discrepancy between the discovery and replication samples is somewhat surprising, given that the samples came from the same recruitment source and were well matched in demographic characteristics. Hence, if this effect does exist it appears weaker than our smallest effect size of interest and further replication efforts will be critical.

Despite not being consistently observed in both samples, the *potential* enhancing effects observed in the ECSA, when considered alongside the findings in our unrelated condition, do align with predictions

from prior models elucidating the influence of priority on the retroactive effects of emotion on memory (Mather et al., 2016; Mather & Sutherland, 2011). Again, in the present study, priority was mediated by the conceptual relatedness of the preceding stimulus, which we believed would dictate the predictive utility of the item and in turn, its priority (Palombo & Cocquyt, 2020) as suggested by prior empirical work by Smith and Beversdorf (2008). The role of predictions in memory for emotional events have been emphasised as a mechanism beyond arousal which can influence our memory of emotional events (Kalbe & Schwabe, 2020; Rouhani et al., 2023). These memories, which encompass the predictions we made and the actual outcomes, interact with our relational and conceptual knowledge to aid in inferring danger in future situations (Baczkowski et al., 2023). As such, the related condition would reflect high predictive utility, thus high priority (and the unrelated condition would reflect low predictive utility, thus low priority).

The underlying process that may support an effect of emotion in the relatedness condition (when observed) could reflect similar mechanisms proposed for the unrelated condition but manifesting in an opposing manner: For example, the effect of emotion within the relatedness condition might be related to working memory, wherein the preceding items are spared from emotion-induced working memory flushing noted earlier (Dolcos & McCarthy, 2006). Perhaps the preceding test items remain longer (or are reactivated) in working memory to determine the conceptual linkages between the test item and the modulator. Beyond possible maintenance of these items in working memory, these effects might also be mediated by consolidation processes as highlighted in the *glutamate amplifies noradrenergic effects* (GANE) model (Mather et al., 2016). This model suggests that high-priority items preceding an emotional event benefit from a noradrenergic mediated boost in consolidation, whereas low-priority items incur a depression in consolidation (see Mather et al., 2016 for further neurobiological details of this model). Thus, the GANE model is potentially relevant to our results in both the related and unrelated conditions.

Given the 24-hour delay, it is unclear whether such effects are mediated by earlier versus more protracted consolidation processes, such as those occurring during sleep. Specifically, stimuli retroactively perceived as having high predictive utility for an

emotional outcome can be preferentially tagged as high priority for later consolidation, in a selection process termed “adaptive consolidation” (Cowan et al., 2021; Dunsmoor et al., 2022). These consolidation mechanisms allow for items encountered prior to an emotional event to be revisited and reinforced during sleep and memory replay, strengthening their representation in memory (Cowan et al., 2021; Dunsmoor et al., 2022). Whereas prior work suggests that such delayed consolidation mechanisms are required to modulate memory for conceptually related content in block designs (e.g. see Dunsmoor et al., 2015), we did not manipulate retention interval in the present study and thus do not know what aspects of consolidation are necessary or sufficient to produce our effects.

Many of the models and mechanisms outlined above highlight the key role of emotional arousal in initiating the prioritisation processes that support retroactive enhancements vs. impairments. Accordingly, our data suggests that the conceptual relatedness of the preceding stimuli was only relevant in influencing memory when the subsequent image was emotional. Specifically, memory was weaker for items preceding emotional stimuli when they were unrelated than when related, whereas there were no relatedness effects on memory performance in the neutral condition. This effect was most striking in the ECSA, wherein the means in the two neutral conditions are almost identical, suggesting that relatedness in the context of a neutral event, like other forms of priority, may not influence memorability.

Still, in considering the results within the relatedness condition, we must emphasise that the ECSA was not part of our registered methodology. Thus, in light of the statistical disparities between our two independent samples and the exploratory nature of the ECSA, it is also possible that the retroactive effect of emotion on memory in the relatedness condition in the discovery sample (and the ECSA) was a false positive. If this were so, though, our data still allow us to posit that the differential effects observed in the related versus unrelated conditions may – at a minimum – reflect a “rescuing” effect of conceptual relatedness when emotion is a factor at play (i.e. rather than a hypothesised “boosting” effect). In other words, the high predictive utility of related stimuli may rescue (or more aptly, “protect”) items from the retroactive impairment noted in the unrelated condition, with items preceding negative stimuli being impaired when unrelated but not

when related. Put another way, negative emotion has less of an overshadowing penumbra effect on memory when contiguous stimuli are conceptually linked. With such an interpretation under consideration, application of the aforementioned models (e.g. GANE) to explain our findings in the relatedness condition should be done so judiciously as those models would predict higher performance in the negative versus neutral condition and we only observed that pattern in one of our samples.

More broadly, a critical consideration when interpreting our results revolves around whether conceptual relatedness modulates the priority of preceding stimuli in a manner consistent with earlier research paradigms. In our study, we employed relatedness as a means to adjust the predictive utility of the preceding item and, consequently, its priority (also see Smith & Beversdorf, 2008).¹⁰ Unlike other previous investigations that manipulated priority through explicit instructions, such as posing orienting questions towards preceding items (e.g. “Will you remember this image?”; Anderson et al., 2006) or adjusting task demands (e.g. “Please remember the object right before the black-framed picture”; Sakaki et al., 2014), our study, and that of Smith and Beversdorf (2008), implicitly manipulated priority via bolstering (or attenuating) semantic relationships between encoded items. The utilisation of a between-subjects design in the present study may have contributed further to the implicit nature of our manipulation: Participants in each relatedness group were not exposed to trials that markedly differed in their relatedness, minimising attention drawn to this distinction. Meticulous attention to between-trial variability could be a pivotal element in fortifying memory for high-priority items. It is plausible that the presence of a related item among other related pairs dilutes its perceived priority to the individual, while intermixing related and unrelated items may accentuate this perception. Further, prior work suggests that in order to observe a retroactive boost in memory, the initial memory trace of that item needs to be sufficiently “weak” (Dunsmoor et al., 2022). Potentially, the timing and use of pairwise presentations may have made the memory trace for the preceding items strong enough that it was no longer susceptible to a robust boosting effect (when considering the results of the replication sample), however, previous studies using a very similar paradigm have observed enhancements (e.g. Anderson et al., 2006). The implicit and non-competitive nature of our paradigm

may have posed challenges in detecting a stronger and more consistent within-relatedness effect of emotion across our two samples. Future efforts can be put towards developing a within-subjects version of our 2×2 design, but we note that our own earlier efforts to do so resulted in challenges in fully matching stimuli across conditions.

Perhaps more important than the relatedness of an experience is whether the experience demonstrates a causal relationship (also see Palombo & Cocquyt, 2020) – something we did not directly manipulate in our study. For example, while an image of a mailbox may be conceptually related to an image of a house on fire, it lacks a causal connection. Causal features may exert a distinct influence on whether preceding items are perceived as having predictive utility. Interestingly, a prior study by Brierley et al. (2007) observed that during the recall of words from emotionally charged sentences, participants exhibited superior recall not only for the emotional words but also for neutral words connected to the emotional content. Some of the neutral words appeared causally linked (e.g. the word “teacher” in the sentence, “the teacher made the class afraid”), although this was not the case for all stimuli. Future work should *directly* manipulate the conceptual versus causal relationship between stimuli to determine whether causality is a critical factor.

Beyond conceptual linkages, recent computational models have highlighted that sequential presentation of items close in time (i.e. temporal contiguity) can contribute to potential predictive associations between stimuli, indicating that temporal associations may be sufficient for establishing relationships between neutral and emotional events under some circumstances (Howard et al., 2023; Lohnas & Howard, 2024). The influence of temporal contiguity raises the possibility that our unrelated condition may not have been completely devoid of a predictive association, however, that it may not have emerged to the threshold of “utility” – though the manipulation was sufficient to impair memory. Alternatively, the addition of temporal contingency alongside contiguity (see Howard et al., 2023; Lohnas & Howard, 2024) may allow for an opportunity to look at predictive utility as they pertain to temporal relationships in the absence of a prior semantic relationship but the boundary conditions for such linkages will require further empirical work. More broadly, there is an exciting literature emerging that focuses on the manner in which emotion shapes memory for temporally

contiguous experiences, both retrospectively and prospectively (see Petrucci & Palombo, 2021; also see e.g. Bogdan et al., 2023; de Montpellerier & Talmi, 2023; Lohnas & Howard, 2024; Riegel et al., 2023) but a fulsome discussion of this work is beyond the scope of this paper.¹¹

Interestingly, the effects of conceptual relatedness on memory seems to be unidirectional, with relatedness not showing any effects on memory for the emotional images (i.e. the “modulators”) themselves. This is striking given that the second image is the one which “sets the tone” for that image pair, in that only upon presentation of the second image would participants be aware of the nature of the relationship between them. In light of the large effect size observed in the modulators, it is possible that the emotional enhancement in memory is so strong that it masks any potential influences of relatedness. More broadly, the emotional memory enhancement effect observed here is consistent with other literature showing better memory for emotional versus neutral stimuli (e.g. Adelman & Estes, 2013; Madan et al., 2012, 2017; Palombo et al., 2021; Rimmel et al., 2011; Stewardson et al., 2022; but see Dougal & Rotello, 2007).

A limitation of our study was that it was run online and thus we could not monitor participants during encoding or retrieval. Nonetheless we observed strong psychometric properties in our data (e.g. reasonable distributions; limited ceiling and floor effects). Moreover, the strong manipulation effect, wherein emotional modulators were better remembered than neutral ones, lend itself well to the credibility of our approach and the utility of online data collection.

To close, here we show that conceptual relatedness is an important factor in determining how emotion (in this case, negative emotion) modulates memory for temporally adjacent events. In doing so, we shed light on the complex role that emotion plays in casting both a shadow and potentially a spotlight on facets of our unfolding experiences, contingent on the context.

Notes

1. Emotion can also have anterograde effects on subsequent stimuli but such effects are not discussed here (Cleworth et al., 2017; Hurlmann et al., 2005, 2007; Knight & Mather, 2009; Miu et al., 2005; Müller et al., 2009; Sakaki et al., 2014; Smith & Beversdorf, 2008; Strange et al., 2003; for a review, see Schlüter et al., 2019).

2. Impairing retrograde effects of emotion are more consistent for negative (versus positive) stimuli (see Schlüter et al., 2019). For example, Hurlemann et al. (2005) observed that negatively valenced stimuli elicited a retrograde impairment, whereas positively valenced stimuli elicited a retrograde enhancement; alternatively Sakaki et al. (2014) observed a retroactive impairment for both negative and positive stimuli.
3. As noted by Schlüter et al. (2019) methodological limitations may have played a role in the pattern of results observed in Smith and Beversdorf (2008), including a possible role of rehearsal, given the short word lists and intentional encoding design inherent to oddball paradigms (which may have promoted rehearsal). We also note that Smith and Beversdorf (2008), albeit elegant, was a small study of $N=28$ participants and thus conceptual replication of the phenomena is important.
4. In two places in the Qualtrics component of the study (randomly placed in the demographics and health screen; see Main Text), participants were asked to type the word “Venus” and “Saturn”.
5. This criterion aimed to identify individuals who were not adequately engaged in the task. 24 trials accounts for 15% of the total trials.
6. Participants also completed the Center for Epidemiologic Studies Depression Scale (CES-D; Radloff, 1977), and the State-Trait Anxiety Inventory for Adults (STAI; Spielberger et al., 1983) as part of our general lab protocol; however these surveys are not discussed here.
7. An initial version of this study was conducted in our laboratory; however, in this study (unpublished MA thesis), we did not have perfect counterbalancing between conditions or subsequent stimulus balancing. The current study aims to address these concerns via the proposed norming study detailed in the Supplemental Information.
8. Our design differs in an important way from Anderson et al. (2006) in that we do not have an orienting task for the “test” items. This design choice was deliberate in that we wanted to isolate the priority-inducing effects of semantic relatedness, as opposed to priority induced by task instructions.
9. This analysis was not prescribed in the accepted Stage 1 Registered Report but was added at Stage 2 to bolster clarity in our results.
10. Other work focusing on conceptual relationships has investigated a more protracted phenomena where conceptual linkages modulate memory over longer delays during encoding (i.e. as observed in blocked designs; see e.g. Dunsmoor et al., 2015; Clewett et al., 2022). These paradigms are experimentally distinct from the present work but are nonetheless relevant. Findings from these studies have been somewhat mixed in terms of whether stimuli which are conceptually related to a subsequent emotional experience (up to 3 h later) can be subsequently enhanced (Dunsmoor et al., 2015; Patil et al., 2017; Kalbe & Schwabe, 2021; see review by Koevoet & Postma, 2023).
11. Somewhat related to these ideas, it would be interesting to examine more directly the presence of dependency effects between modulator and test items and whether

this differs by condition (e.g. see Caplan et al., 2014; Horner et al., 2015; Ngo et al., 2021). For example, such an analysis could reveal whether negative versus neutral emotion in the unrelated condition significantly decreases test and modulator dependency, aligning with the disruptive effects we observe in our main analyses. Unfortunately, in our dataset, we did not have a sufficient number of missed trials to make this a viable analysis. Future studies with larger delays between encoding and test (or a greater total number of trials) may allow for such a nuanced analysis.

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References

- Adelman, J. S., & Estes, Z. (2013). Emotion and memory: A recognition advantage for positive and negative words independent of arousal. *Cognition*, 129(3), 530–535. <https://doi.org/10.1016/j.cognition.2013.08.014>
- Anderson, A. K., Wais, P. E., & Gabrieli, J. D. E. (2006). Emotion enhances remembrance of neutral events past. *Proceedings of the National Academy of Sciences*, 103(5), 1599–1604. <https://doi.org/10.1073/pnas.0506308103>
- Baczkowski, B. M., Haaker, J., & Schwabe, L. (2023). Inferring danger with minimal aversive experience. *Trends in Cognitive Sciences*, 27(5), 456–467. <https://doi.org/10.1016/j.tics.2023.02.005>
- Bogdan, P. C., Dolcos, S., Federmeier, K. D., Lleras, A., Schwarb, H., & Dolcos, F. (2023). Emotional dissociations in temporal associations: Opposing effects of arousal on memory for details surrounding unpleasant events. *Cognition and Emotion*, 1–15. Advance online publication. <https://doi.org/10.1080/02699931.2023.2270196>

- Brierley, B., Medford, N., Shaw, P., & David, A. S. (2007). Emotional memory for words: Separating content and context. *Cognition and Emotion*, 21(3), 495–521. <https://doi.org/10.1080/02699930600684963>
- Brodeur, M. B., Guérard, K., & Bouras, M. (2014). Bank of standardized stimuli (BOSS) phase II: 930 new normative photos. *PLoS One*, 9(9), e106953–e106953. <https://doi.org/10.1371/journal.pone.0106953>
- Brown, J. M. (2003). Eyewitness memory for arousing events: Putting things into context. *Applied Cognitive Psychology*, 17(1), 93–106. <https://doi.org/10.1002/acp.848>
- Burke, A., Heuer, F., & Reisberg, D. (1992). Remembering emotional events. *Memory & Cognition*, 20(3), 277–290. <https://doi.org/10.3758/BF03199665>
- Caplan, J. B., Rehani, M., & Andrews, J. C. (2014). Associations compete directly in memory. *Quarterly Journal of Experimental Psychology*, 67(5), 955–978. <https://doi.org/10.1080/17470218.2013.838591>
- Christianson, S.-Å., & Loftus, E. F. (1991). Remembering emotional events: The fate of detailed information. *Cognition and Emotion*, 5(2), 81–108. <https://doi.org/10.1080/02699939108411027>
- Clewett, D., Dunsmoor, J., Bachman, S. L., Phelps, E. A., & Davachi, L. (2022). Survival of the salient: Aversive learning rescues otherwise forgettable memories via neural reactivation and post-encoding hippocampal connectivity. *Neurobiology of Learning and Memory*, 187, 107572. <https://doi.org/10.1016/j.nlm.2021.107572>
- Clewett, D., Sakaki, M., Nielsen, S., Petzinger, G., & Mather, M. (2017). Noradrenergic mechanisms of arousal's bidirectional effects on episodic memory. *Neurobiology of Learning and Memory*, 137, 1–14. <https://doi.org/10.1016/j.nlm.2016.10.017>
- Cowan, E. T., Schapiro, A. C., Dunsmoor, J. E., & Murty, V. P. (2021). Memory consolidation as an adaptive process. *Psychonomic Bulletin & Review*, 28(6), 1796–1810. <https://doi.org/10.3758/s13423-021-01978-x>
- Cunningham, W. A., Van Bavel, J. J., & Johnsen, I. R. (2008). Affective flexibility: Evaluative processing goals shape amygdala activity. *Psychological Science*, 19(2), 152–160. <https://doi.org/10.1111/j.1467-9280.2008.02061.x>
- de Montpeller, E., & Talmi, D. (2023). Are multiple types of associative memory differently impacted by emotion? *Cognition and Emotion*, 1–24. <https://doi.org/10.1080/02699931.2023.2279182>
- Dolcos, F., & McCarthy, G. (2006). Brain systems mediating cognitive interference by emotional distraction. *The Journal of Neuroscience*, 26(7), 2072–2079. <https://doi.org/10.1523/JNEUROSCI.5042-05.2006>
- Dougal, S., & Rotello, C. M. (2007). “Remembering” emotional words is based on response bias, not recollection. *Psychonomic Bulletin & Review*, 14(3), 423–429. <https://doi.org/10.3758/BF03194083>
- Dunsmoor, J. E., Murty, V. P., Clewett, D., Phelps, E. A., & Davachi, L. (2022). Tag and capture: How salient experiences target and rescue nearby events in memory. *Trends in Cognitive Sciences*, 26(9), 782–795. <https://doi.org/10.1016/j.tics.2022.06.009>
- Dunsmoor, J. E., Murty, V. P., Davachi, L., & Phelps, E. A. (2015). Emotional learning selectively and retroactively strengthens memories for related events. *Nature*, 520(7547), 345–348. <https://doi.org/10.1038/nature14106>
- Forester, G., Halbeisen, G., Walther, E., & Kamp, S. (2020). Frontal ERP slow waves during memory encoding are associated with affective attitude formation. *International Journal of Psychophysiology*, 158, 389–399. <https://doi.org/10.1016/j.ijpsycho.2020.11.003>
- Horner, A. J., Bisby, J. A., Bush, D., Lin, W. J., & Burgess, N. (2015). Evidence for holistic episodic recollection via hippocampal pattern completion. *Nature Communications*, 6(1), 7462. <https://doi.org/10.1038/ncomms8462>
- Howard, M. W., Esfahani, Z. G., Le, B., & Sederberg, P. B. (2023). *Foundations of a temporal RL*. Cornell University Library, *arXiv.org*. <https://doi.org/10.48550arxiv.2302.10163>
- Hurlmann, R., Hawellek, B., Maier, W., & Dolan, R. J. (2007). Enhanced emotion-induced amnesia in borderline personality disorder. *Psychological Medicine*, 37(7), 971–981. <https://doi.org/10.1017/S0033291706009792>
- Hurlmann, R., Hawellek, B., Matusch, A., Kolsch, H., Wollersen, H., Madea, B., Vogetley, K., Maier, W., & Dolan, R. J. (2005). Noradrenergic modulation of emotion-induced forgetting and remembering. *The Journal of Neuroscience*, 25(27), 6343–6349. <https://doi.org/10.1523/JNEUROSCI.0228-05.2005>
- Kalbe, F., & Schwabe, L. (2020). Beyond arousal: Prediction error related to aversive events promotes episodic memory formation. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 46(2), 234–246. <https://doi.org/10.1037/xlm0000728>
- Kalbe, F., & Schwabe, L. (2021). On the search for a selective and retroactive strengthening of memory: Is there evidence for category-specific behavioral tagging? *Journal of Experimental Psychology: General*, 151(1), 263–284. Advance online publication. <https://doi.org/10.1037/xge0001075>
- Kassambara, A. (2020). *rstatix: Pipe-friendly framework for basic statistical tests* (R package version 0.6.0). <https://CRAN.R-project.org/package=rstatix>
- Kensinger, E. A., Garoff-Eaton, R. J., & Schacter, D. L. (2007). Effects of emotion on memory specificity: Memory trade-offs elicited by negative visually arousing stimuli. *Journal of Memory and Language*, 56(4), 575–591. <https://doi.org/10.1016/j.jml.2006.05.004>
- Kensinger, E. A., Piquet, O., Krendl, A. C., & Corkin, S. (2005). Memory for contextual details: Effects of emotion and aging. *Psychology and Aging*, 20(2), 241–250. <https://doi.org/10.1037/0882-7974.20.2.241>
- Knight, M., & Mather, M. (2009). Reconciling findings of emotion-induced memory enhancement and impairment of preceding items. *Emotion*, 9(6), 763–781. <https://doi.org/10.1037/a0017281>
- Koevoet, D., & Postma, A. (2023). Is there selective retroactive memory enhancement in humans?: A meta-analysis. *Psychonomic Bulletin & Review*, 31(2), 531–540. <https://doi.org/10.3758/s13423-023-02372-5>
- LaBar, K. S., & Cabeza, R. (2006). Cognitive neuroscience of emotional memory. *Nature Reviews Neuroscience*, 7(1), 54–64. <https://doi.org/10.1038/nrn1825>
- Levine, L. J., & Edelman, R. S. (2009). Emotion and memory narrowing: A review and goal-relevance approach. *Cognition and Emotion*, 23(5), 833–875. <https://doi.org/10.1080/02699930902738863>

- Liu, D. L. J., Graham, S., & Zorawski, M. (2008). Enhanced selective memory consolidation following post-learning pleasant and aversive arousal. *Neurobiology of Learning and Memory*, 89(1), 36–46. <https://doi.org/10.1016/j.nlm.2007.09.001>
- Lohnas, L. J., & Howard, M. W. (2024). The influence of emotion on temporal context models. *Cognition and Emotion*, 1–29. <http://doi.org/10.1080/02699931.2024.2371075>
- Macmillan, N. A., & Kaplan, H. L. (1985). Detection theory analysis of group data: Estimating sensitivity from average hit and false-alarm rates. *Psychological Bulletin*, 98(1), 185–199. <https://doi.org/10.1037/0033-2909.98.1.185>
- Madan, C. R. (2024). *Memories that matter: How we remember important things*. Routledge. <https://doi.org/10.4324/9780429032028>
- Madan, C. R., Caplan, J. B., Lau, C. S. M., & Fujiwara, E. (2012). Emotional arousal does not enhance association-memory. *Journal of Memory and Language*, 66(4), 695–716. <https://doi.org/10.1016/j.jml.2012.04.001>
- Madan, C. R., Fujiwara, E., Caplan, J. B., & Sommer, T. (2017). Emotional arousal impairs association-memory: Roles of amygdala and hippocampus. *NeuroImage*, 156, 14–28. <https://doi.org/10.1016/j.neuroimage.2017.04.065>
- Madan, C. R., Knight, A. G., Kensingler, E. A., & Mickley Steinmetz, K. R. (2020). Affect enhances object-background associations: Evidence from behaviour and mathematical modelling. *Cognition and Emotion*, 34(5), 960–969. <https://doi.org/10.1080/02699931.2019.1710110>
- Marchewka, A., Żurawski, Ł., Jednoróg, K., & Grabowska, A. (2014). The Nencki Affective Picture System (NAPS): Introduction to a novel, standardized, wide-range, high-quality, realistic picture database. *Behavior Research Methods*, 46(2), 596–610. <https://doi.org/10.3758/s13428-013-0379-1>
- Mather, M., Clewett, D., Sakaki, M., & Harley, C. W. (2016). Norepinephrine ignites local hotspots of neuronal excitation: How arousal amplifies selectivity in perception and memory. *Behavioral and Brain Sciences*, 39, e200. <https://doi.org/10.1017/S0140525X15000667>
- Mather, M., & Sutherland, M. R. (2011). Arousal-biased competition in perception and memory. *Perspectives on Psychological Science*, 6(2), 114–133. <https://doi.org/10.1177/1745691611400234>
- McGaugh, J. L. (2004). The amygdala modulates the consolidation of memories of emotionally arousing experiences. *Annual Review of Neuroscience*, 27(1), 1–28. <https://doi.org/10.1146/annurev.neuro.27.070203.144157>
- Miu, A. C., Heilman, R. M., Opre, A., & Miclea, M. (2005). Emotion-induced retrograde amnesia and trait anxiety. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 31(6), 1250–1257. <https://doi.org/10.1037/0278-7393.31.6.1250>
- Müller, N. G., Wohlrath, B., Kopp, U. A., & Lengler, U. (2009). Emotional content does not interfere with verbal memory in patients with temporal lobe epilepsy. *Epilepsy & Behavior*, 15(3), 367–371. <https://doi.org/10.1016/j.yebeh.2009.05.006>
- Ngo, C. T., Michelmann, S., Olson, I. R., & Newcombe, N. S. (2021). Pattern separation and pattern completion: Behaviorally separable processes? *Memory & Cognition*, 49(1), 193–205. <https://doi.org/10.3758/s13421-020-01072-y>
- Nielson, K. A., & Powless, M. (2007). Positive and negative sources of emotional arousal enhance long-term word-list retention when induced as long as 30min after learning. *Neurobiology of Learning and Memory*, 88(1), 40–47. <https://doi.org/10.1016/j.nlm.2007.03.005>
- Nielson, K. A., Yee, D., & Erickson, K. I. (2005). Memory enhancement by a semantically unrelated emotional arousal source induced after learning. *Neurobiology of Learning and Memory*, 84(1), 49–56. <https://doi.org/10.1016/j.nlm.2005.04.001>
- Palombo, D. J., & Cocquyt, C. (2020). Emotion in context: Remembering when. *Trends in Cognitive Sciences*, 24(9), 687–690. <https://doi.org/10.1016/j.tics.2020.05.017>
- Palombo, D. J., Elizur, L., Tuen, Y. J., Te, A. A., & Madan, C. R. (2021). Transfer of negative valence in an episodic memory task. *Cognition*, 217, 104874. <http://doi.org/10.1016/j.cognition.2021.104874>
- Patil, A., Murty, V. P., Dunsmoor, J. E., Phelps, E. A., & Davachi, L. (2017). Reward retroactively enhances memory consolidation for related items. *Learning & Memory (Cold Spring Harbor, N.Y.)*, 24(1), 65–69. <https://doi.org/10.1101/lm.042978.116>
- Petrucci, A. S., & Palombo, D. J. (2021). A matter of time: How does emotion influence temporal aspects of remembering? *Cognition & Emotion*, 35(8), 1499–1515. <https://doi.org/10.1080/02699931.2021.1976733>
- Pickel, K. L., French, T. A., & Betts, J. M. (2003). A cross-modal weapon focus effect: The influence of a weapon's presence on memory for auditory information. *Memory (Hove, England)*, 11(3), 277–292. <https://doi.org/10.1080/09658210244000036>
- Pierce, J., Gray, J. R., Simpson, S., MacAskill, M., Höchenberger, R., Sogo, H., Kastman, E., & Lindeløv, J. K. (2019). Psychopy2: Experiments in behavior made easy. *Behavior Research Methods*, 51(1), 195–203. <https://doi.org/10.3758/s13428-018-01193-y>
- Radloff, L. S. (1977). The CES-D scale: A self-report depression scale for research in the general population. *Applied Psychological Measurement*, 1(3), 385–401. <https://doi.org/10.1177/014662167700100306>
- R Core Team. (2019). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. <https://www.R-project.org/>
- Reisberg, D., & Heuer, F. (2004). *Memory for emotional events. Memory and emotion* (pp. 3–41). Oxford University Press. <https://doi.org/10.1093/acprof:oso/9780195158564.003.0001>
- Riegel, M., Granja, D., Amer, T., Vuilleumier, P., & Rimele, U. (2023). Opposite effects of emotion and event segmentation on temporal order memory and object-context binding. *Cognition and Emotion*, 1–19. Advance online publication. <https://doi.org/10.1080/02699931.2023.2270195>
- Rimele, U., Davachi, L., Petrov, R., Dougal, S., & Phelps, E. A. (2011). Emotion enhances the subjective feeling of remembering, despite lower accuracy for contextual details. *Emotion*, 11(3), 553–562. <http://doi.org/10.1037/a0024246>
- Rouhani, N., Niv, Y., Frank, M. J., & Schwabe, L. (2023). Multiple routes to enhanced memory for emotionally relevant events. *Trends in Cognitive Sciences*, 27(9), 867–882. <https://doi.org/10.1016/j.tics.2023.06.006>
- Sakaki, M., Fryer, K., & Mather, M. (2014). Emotion strengthens high-priority memory traces but weakens low-priority memory traces. *Psychological Science*, 25(2), 387–395. <https://doi.org/10.1177/0956797613504784>

- Schlüter, H., Hackländer, R. P., & Bermeitinger, C. (2019). Emotional oddball: A review on memory effects. *Psychonomic Bulletin & Review*, 26(5), 1472–1502. <https://doi.org/10.3758/s13423-019-01658-x>
- Smith, R. M., & Beversdorf, D. Q. (2008). Effects of semantic relatedness on recall of stimuli preceding emotional oddballs. *Journal of the International Neuropsychological Society: JINS*, 14(4), 620–628. <https://doi.org/10.1017/S1355617708080843>
- Spielberger, C. D., Gorsuch, R. L., Lushene, R., Vagg, P. R., & Jacobs, G. A. (1983). *Manual for the state-trait anxiety inventory*. Consulting Psychologists Press.
- Stewardson, C. I., Hunsche, M. C., Wardell, V., Palombo, D. J., & Kerns, C. M. (2022). Episodic memory through a social and emotional lens. *Emotion*, 23(4), 961–972. <https://doi.org/10.1037/emo0001147>
- Strange, B. A., Hurlmann, R., & Dolan, R. J. (2003). An emotion-induced retrograde amnesia in humans is amygdala- and β -adrenergic-dependent. *Proceedings of the National Academy of Sciences*, 100(23), 13626–13631. <https://doi.org/10.1073/pnas.1635116100>
- Strange, B. A., Kross, M. C. W., Fan, J. E., & Dolan, R. J. (2010). Emotion causes targeted forgetting of established memories. *Frontier in Behavioral Neuroscience*, 4, 175. <https://doi.org/10.3389/fnbeh.2010.00175>
- Tulving, E. (1969). Retrograde amnesia in free recall. *Science*, 164(3875), 88–90. <https://doi.org/10.1126/science.164.3875.88>
- Wang, B., & Ren, Y. (2017). Effect of post-encoding emotion on recollection and familiarity for pictures. *Quarterly Journal of Experimental Psychology*, 70(7), 1236–1253. <https://doi.org/10.1080/17470218.2016.1178311>
- Wickham, H. (2016). *Ggplot2: Elegant graphics for data analysis*. Springer-Verlag. ISBN: 978-3-319-24277-4.
- Wixted, J. T. (2007). Dual-process theory and signal-detection theory of recognition memory. *Psychological Review*, 114(1), 152–176. <https://doi.org/10.1037/0033-295X.114.1.152>
- Yonelinas, A. P., & Ritchey, M. (2015). The slow forgetting of emotional episodic memories: An emotional binding account. *Trends in Cognitive Sciences*, 19(5), 259–267. <https://doi.org/10.1016/j.tics.2015.02.009>