UNDERSTANDING THE RETROGRADE EFFECTS OF EMOTION ON MEMORY FOR RELATED EVENTS

by

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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 happened before an emotional event. Recently proposed theories suggest that emotion can retroactively enhance memory for preceding neutral events if they are deemed *high priority,* whilst impairing memory for those deemed *low priority.* However, the effects of the conceptual relationship between preceding neutral and emotional events on memory for the preceding information have yet to be investigated. Conceptual relatedness refers to the extent to which stimuli are connected either semantically or schematically. In this study, I investigated the effects of conceptual relatedness on the retroactive effects of emotion on memory. To do so, I used a unique paradigm where participants sequentially encoded pairs of images that were either related or unrelated. The first image was always neutral, whereas the second image was either negative or neutral. Participants then returned 24 hours later to complete a recognition memory assessment. Consistent with prior research on emotional memory, emotional images were remembered better than neutral images. Additionally, in support of our hypothesis, emotion enhanced memory for preceding images that were related, however it impaired memory for preceding images that were unrelated. These findings indicate that the effects of emotion on memory for preceding events are dependent on the conceptual relationship between them.

Lay Summary

When people experience an emotional event, they typically remember the emotional event itself, but what about the events that occurred before? Some theories suggest that these events are remembered differently depending on the priority we assign to them. More specifically, information encountered before an emotional event will be remembered better if it is considered *high priority* but not if it is deemed *low priority*. I tested whether the strength of the conceptual relationship between preceding events and the emotional experience can influence how well those preceding events are remembered. Conceptual relatedness refers to strength of the semantic associations between stimuli. Emotion enhanced memory for preceding information if that information was related, and impaired memory if that information was unrelated. These findings highlight the important role of conceptual relatedness in the retroactive effects of emotion on memory.

Preface

This study was designed and conceptualized by myself in collaboration with my adviser Dr. Daniela Palombo and our collaborator Dr. Christopher Madan. Data analyses was performed by me with supervision from Dr. Daniela Palombo. I was also assisted by Alessandra Te for data checking and Bonnie Densmore assisted with data collection.

This project was conducted online in the Memory and Imagination Lab at the University of British Columbia with approval from the UBC Behavioural Research Ethics Board (H19-01357).

Table of Contents

List of Tables

List of Figures

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Dedication

To my loving parents, Ken and Elly, for making me the woman I am today. You mean the world to me.

Chapter 1: Introduction

1.1 General Introduction

It is well established that emotion enhances some aspects of memory (Adelman & Estes, 2013; Christianson & Loftus, 1991; Easterbrook, 1959; Kensinger et al., 2007; McGaugh, 2004; Reisberg & Heuer, 2004; see LaBar & Cabeza, 2006, 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 dog). However, emotion does not only influence our memory for the emotion-inducing event per se, it can also colour memory for experiences that occur prior to an emotional event, such as a barrel you saw on the path moments before your encounter with the snake. Studies investigating such retroactive effects of emotion on neutral memory have yielded mixed results. Whereas some studies have found that emotion retroactively *impairs* memory, others show that emotion retroactively *enhances* memory. As detailed below, the purpose of this thesis is to explore further the retroactive effects of emotion on memory.

1.2 Emotional Enhancements in Memory for Emotional Stimuli

The memory enhancements that have been observed for emotional events per se have been attributed to a multitude of processes at every stage of memory including attention, consolidation, and retrieval (Levine & Edelstein, 2009). With respect to attention, prior studies have suggested that individuals show attentional biases toward emotional stimuli during encoding, and this is part of what drives emotional enhancements in memory (Schmidt & Saari, 2007; Todd et al., 2012). The attentional biases towards emotional stimuli have been supported by studies demonstrating that emotional stimuli are resistant to the attentional blink effect

(Anderson, 2005; Anderson & Phelps, 2001) and by studies using EEG which have found that neural responses to emotional stimuli have a shorter latency than to neutral stimuli (Koster et al., 2007; Ohman, & Soares, 1998). The importance of attention is further highlighted by work from Sharot and Phelps (2004) who found that when attention was controlled for, and participants were tested immediately, the emotional enhancement on memory was no longer present (also see Talmi & McGarry, 2012).

Emotional enhancements in memory cannot, however, be accounted for by attention alone. For instance, that same study by Sharot and Phelps (2004) found that although the emotional enhancement effect was not present when tested immediately when attention was controlled for, this enhancement was evident when participants were tested 24 hours later. This finding suggests that post-encoding processes also play a vital role in the enhancing effects of emotion. Indeed, multiple studies suggest that emotion strengthens memories over time, whereas our memories of neutral items tend to fade (Kleinsmith & Kaplan, 1963; LaBar & Cabeza, 2006; LaBar & Phelps, 1998). Several post-encoding processes can contribute to the strengthening of emotional memories over time, including rehearsal and cellular consolidation. With respect to rehearsal, evidence suggests that rehearsal can help memories become more solidified in long-term memory and that individuals are more likely to rehearse emotional memories relative to neutral ones (Finkenauer et al., 1998; Rime et al., 1991). However, emotional memories have been found to strengthen over time even when controlling for rehearsal, thus suggesting that rehearsal is not the only contributor to this effect (Guy & Cahill, 1999).

Turning to cellular consolidation—the biochemical process that strengthens memories and makes them more likely to stand the test of time—a wealth of data shows that emotion alters how memories are consolidated. For example, emotional or salient events activate the sympathetic nervous system causing the release of hormones and activating noradrenergic systems in the amygdala, a region that mediates the consolidation of long-term memory (Cahill et al., 1994; see McGaugh, 2004 for a review). The amygdala is crucial for strengthening salient memories, with studies finding that lesions to the amygdala attenuate the enhancing effects of arousal-related hormones on memory (McGaugh, 2004). In short, the combination of quick-acting mechanisms such as attention (Talmi et al., 2007) and longer-term mechanisms such as rehearsal (Finkenauer et al., 1998; Rime et al., 1991) and cellular consolidation (McGaugh, 2004), as well as retrieval processes (Talmi, 2013) all contribute to the emotional memory enhancements (also see Todd et al., 2020 for review).

1.3 Effects of Emotion on Related Neutral Experiences

The same mechanisms that lead to enhancements in memory for emotional information, however, may also contribute to memory impairments for neutral details *surrounding* an emotional event (Revelle & Loftus, 1992; Talmi, 2013). More specifically, some studies have found that neutral information presented in close spatial or temporal proximity to an emotional event is less likely to be remembered due to the attentional demands of emotional stimuli not leaving adequate cognitive resources to process the surrounding neutral information (Burke et al., 1992; Kensinger et al., 2007; but see Madan et al., 2012). For example, if an image of a snake is presented on a neutral background, individuals are likely to remember the emotionally salient snake, however, memory for background details is likely to be impaired (often referred to as a central-peripheral trade off). This narrowing of focus towards central emotional details leads to inattentional blindness where peripheral details are less likely to be encoded (Kensinger et al., 2007; Mather, 2007; Waring & Kensinger, 2011). This central-peripheral tradeoff is present in emotional, but not neutral scenes (Brown, 2003; Easterbrook, 1959; Kensinger et al., 2005; Mather & Sutherland, 2011; Pickel et al., 2003). These effects of emotion on memory are especially prominent when the emotional stimulus is negatively arousing (Kensinger, 2007; Kensinger et al., 2006). Beyond the attentional biases that may contribute to this impairment for neutral contextual details, neutral details are further disadvantaged in memory as they do not benefit from the amplifying effects of amygdala activation (relative to emotional details) that aid in strengthening memory traces (Cahill et al., 1994; LaBar & Phelps, 1998). Overall, emotion seems to enhance memory for central emotional details, while impairing memory for peripheral neutral details (Levine, & Edelstein, 2009).

Memory for peripheral neutral details, however, is not always impaired; alternatively, memory for these details can be enhanced if those details are considered *goal-relevant*. That is, neutral information that is relevant to one's goals at the time of encoding can escape inattentional blindness and experience a memory enhancement (Brierley et al., 2007; Burke et al., 1992; Christianson et al., 1991; Hockey, 1970; Koivisto & Revonsuo, 2007; Mather & Sutherland, 2011). Goal-relevant stimuli, regardless of valence, can increase amygdala activation (Cuningham et al., 2008) and noradrenergic activity (Clewett et al., 2017) which can bolster it in memory. As noted in the next section, the 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.

1.4 Retrograde Effects of Emotion

Real-world experiences do not occur in a vacuum. Our experiences unfold in a context with a continuous stream of events occurring before, during, and after an emotional event. As in the aforementioned example, in the real world, you would encounter stimuli before you observe the snake. In this temporal context, emotion has been found to 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.

These studies have, however, yielded seemingly conflicting findings. Whereas some earlier work has shown that that emotion retroactively enhances memory (Anderson et al., 2006; Dunsmoor et al., 2015; Forester et al., 2020; Knight & Mather, 2009; Neilson & Powless, 2007; Neilson, Yee, & Erickson, 2005; Sakaki et al. 2014), other studies show that it impairs or has no effect on memory (Hurlemann et al., 2005; Miu et al., 2005; Strange et al., 2003; Strange et al., 2010; Tulving, 1969; Wang & Ren, 2017). Although there have been theories proposed that aid our understanding of these conflicting results (detailed below), the boundary conditions for this effect require further investigation. The purpose of this thesis is to better understand the conditions under which there are emotional retroactive memory enhancements vs. impairments.

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; Strange et al., 2010; Tulving, 1969). For example, a study by 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, norepinephrine (NE) induced activation of the bilateral amygdala may lead to a diversion of cognitive resources to processing the emotional event (Hurlemann et al., 2005; Miu et al., 2005; Strange et al., 2003). Possible support for this mechanism was found in the Strange et al. (2003) study where they found that they could block or exacerbate these impairment effects by manipulating arousal responses through central NE via adrenoreceptor antagonists and agonists. Specifically, the authors observed that the NE antagonist reduced arousal and blocked the impairment effects whereas the agonist increased arousal and made the impairment effects more pronounced. In another study using a block design, Wang and Ren (2017) observed an impairment for both negative and neutral images that were viewed 10 minutes prior to a negative video. However, given that the negative and neutral images were intermixed at encoding, the negative images might have acted to inadvertently interrupt the consolidation of the neutral stimuli. Given that these impairing effects of emotion have been observed in diverse paradigms with varied temporal proximity between preceding information and the emotional event, it suggests that there may be multiple mechanisms contributing to these impairment effects.

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), researchers sequentially presented pairs of images, where the latter was either negative or neutral, and assessed recognition memory for the preceding images one week later. In this study, they found retrograde memory enhancements 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, which is a more immediate response to emotional arousal than stress hormones. Thus, the same arousal that has been thought to contribute to emotional retroactive memory impairments, has also been thought to contribute to retroactive memory enhancements.

Other researchers have suggested that these enhancements are more likely due to the priority of preceding information, which can be dictated by the bottom-up salience or goal-relevance of the preceding information (Sakaki et al., 2014). 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 prioritize 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 prioritize 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.

What are the underlying neural mechanisms that presuppose the modulating effect of priority? One theory that could potentially account for these findings is the *glutamate amplifies noradrenergic effects* (GANE) model developed by Mather et al. (2016a). This model indicates that, under arousal, activation in the locus coeruleus (LC; hub for integrating arousal signals) stimulates diffuse release of NE along its noradrenergic axons. In tandem, when a stimulus is assessed as high priority, neurons release greater levels of glutamate than low-priority items. These higher levels of glutamate in return stimulate increased local release of NE beyond what would be released via LC activation alone to create *NE hotspots*. These NE hotspots activate low-affinity β-adrenergic receptors and facilitate long-term potentiation to enhance memory for high priority information. In contrast, lower NE levels, as would be expected for low-priority representations, leads to activation of high-affinity α1-adrenergic receptors that facilitate long-term depression resulting in a weaker representation. Thus, the GANE model offers insight into how emotional arousal can differentially affect memory for preceding information (Mather et al., 2016a).

It is important to note, however, that these enhancements have also been observed in studies using block paradigms suggesting a more far-reaching effect of emotion on memory (Dunsmoor et al., 2015; Neilson et al., 2007; Wang, 2018), with emotion colouring our memory for stimuli encountered up to 30 minutes prior to an emotional event (Neilson & Powless, 2007).

These studies indicate that there may be an additional alternative mechanism, one that relies on longer-term consolidation processes that are only present after a delay, and do not occur immediately following encoding. (Dunsmoor et al., 2015; Neilson & Powless, 2007).

1.5 Current Study

The GANE model (Mather et al., 2016a) alongside behavioural studies (Knight & Mather, 2009; Sakaki et al., 2014) have elucidated the mechanisms that underlie the mixed findings on the retroactive effects of emotion on memory, emphasizing the influence of the priority of preceding information. This model opens the door to build on this research and investigate how one can modulate the priority of preceding information, thus influencing how we remember it. I proposed that the conceptual relationship between preceding information and an emotional event is a factor that can modulate the amount of priority (goal-relevance) adopted by the preceding item. 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 are unknown (for related ideas see Dunsmoor et al., 2015; Smith & Beversdorf, 2008).

When real life experiences unfold, there is a continuous flow of events that can allow for the perception of causal links between stimuli (Liu et al., 2008; Reisberg & Heuer, 2004). In other words, preceding stimuli can adopt predictive utility, in that it becomes a useful indicator of threat in future situations thus prioritizing it in memory (Palombo & Cocquyt, 2020). 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. Preceding stimuli, such as a mitten, may be retroactively deemed to have low predictive utility since there is no perceived relationship to the snake. Alternatively, preceding stimuli, such as a tipped over barrel, may be retroactively deemed to have high predictive utility given its potential relationship to the snake (perhaps that is where the snake had come from; Levine & Edelstein, 2009).

Accordingly, the goal of the current study is to investigate how conceptual relatedness and valence interact to influence memory for preceding information. I hypothesize that emotion will enhance memory for neutral images preceding conceptually related images (high predictive utility) and impair memory for neutral images preceding conceptually unrelated images (low predictive utility).

Additionally, an ancillary goal of the current study is to assess how emotion not only influences *explicit* processes such as recognition memory, but also *implicit* memory processes such as 'transfer of valence'. Transfer of valence is a term coined in our lab for the process by which emotion can change one's perceptions and attitudes towards neutral experiences (Palombo et al., under revision). Prior work on evaluative conditioning (the acquisition of preferences via direct conditioning; Baeyens et al., 1992) has indicated that there can also be a spreading of attitude effect where neutral stimulus that is indirectly associated with a negative stimulus can implicitly adopt the negative valence from the negative stimulus (Walther, 2002). Further, it has been observed using verbal stimuli that this transfer of valence can occur retroactively when a neutral word is followed by an emotional word, but only when the emotional word was positive (Forester et al., 2020). Yet, it is not known whether this effect can work retroactively using visual stimuli, as in our paradigm. Accordingly, a subsidiary goal for this study is to assess whether the valence of emotional items ‘spills over’ to the neutral image that precedes it and whether such a spill over depends on conceptual relatedness.

Chapter 2: Methods

2.1 Participants

This study was approved by the Behavioural Ethics Board at the University of British Columbia (UBC). This experiment consisted of two independent cohorts of participants hereafter referred to as Cohort A and Cohort B. Cohort A was the initial sample, with Cohort B being introduced to address ceiling effects observed in Cohort A. All participants were recruited via the UBC Human Subject Pool (HSP).

Participants were excluded if they performed below chance on the recognition task (accuracy below 50%) and if the trial-wise differences (TWD; the absolute difference between ratings for consecutive trials) for pleasantness ratings in the transfer-of-valence task (see below) were too similar between trials. This calculation was used to exclude participants who repeatedly clicked the same or similar response on every trial. Participants were excluded if their TWD had a standard deviation below 0.3 or they had a TWD of less than 1% for more than 35% of trials.

For Cohort A, there were a total of 26 participants excluded (4 recognition exclusions, 22 TWD exclusions) leaving us with a final sample of 71 participants (M_{age} = 20.77, SD_{age} = 3.15; 61 female, 10 male). For Cohort B, there were a total of 26 participants excluded (8 recognition exclusions, 18 TWD exclusions) leaving us with a final sample of 82 participants (M_{age} = 20.49, SD_{age} = 2.54; 1 gender fluid, 68 female, 13 male).

2.2 Materials

2.2.1 Surveys

Participants completed a series of questionnaires, administered via Qualtrics. Participants completed a demographics and health screen questionnaire developed by our laboratory to characterize our samples. They also completed the Center for Epidemiologic Studies Depression Scale-Revised (CESD-R-20; Eaton et al., 2004), and the State-Trait Anxiety Inventory for Adults (STAI; Spielberger et al., 1977), however these surveys were not analyzed in this study.

2.2.2 Stimuli

The memory paradigm used in this study was modelled after Anderson et al. (2006) and involved participants sequentially viewing pairs of images. The stimuli for this study included a set of images derived from the Nencki Affective Picture System database (NAPS; with permission; Eaton et al., 2004). The stimuli set for Cohort A included a total of 96 NAPS images, of which 48 were negative and 48 were neutral. The stimuli set for Cohort B included a set of 120 NAPS images, of which 60 were negative and 60 were neutral. The NAPS images fall into one of five categories; animals, faces, landscapes, objects, and people (for category breakdown for each valence condition see Table 1). Analyses were conducted to ensure there

Table 1.
NAPS image categories.

Cohort A

Valence	Animals	Faces	Landscapes	Objects	People	Total
Negative	10	7	3	14	14	48
Neutral	12	8	5	11	12	48

Cohort B

Valence	Animals	Faces	Landscapes	Objects	People	Total
Negative	12	10	3	17	18	60
Neutral	13	9	6	14	18	60

Note: Number of NAPS images in each category. Each category indicates what is presented in the image.

Table 2.
NAPS image properties.

Cohort A

Property	Negative		Neutral	
	Mean	SD	Mean	SD
Valence	2.52**	0.45	5.40**	0.61
Arousal	6.78**	0.52	4.66**	0.41
Luminance	120.37	28.50	118.51	32.29
Contrast	62.21	11.18	65.39	12.65
Entropy	7.56	0.38	7.54	0.31
LAB-L	49.77	11.55	48.71	12.86
LAB-A	2.81	4.77	2.03	4.15
LAB-B	7.50	9.82	4.88	9.27

Cohort B

Property	Negative		Neutral	
	Mean	SD	Mean	SD
Valence	2.55**	0.46	5.40**	0.60
Arousal	6.77**	0.52	4.69**	0.40
Luminance	118.42	27.45	115.11	32.99
Contrast	62.60	11.16	65.08	12.20
Entropy	7.58	0.35	7.52	0.34
LAB-L	48.97	11.09	47.32	13.22
LAB-A	2.79	4.63	1.53	4.62
LAB-B	7.34	9.60	5.56	9.03

Note: LAB refers to the CIE L*a*b* colour space (Tkalcic & Tasic, 2003). The L dimension refers to luminance, while A and B are channels ranging from red to green (A), or blue to yellow (B). The mean of these properties is the average across all pixels in the image. Negative and neutral images were significantly different in valence and arousal (as denoted by **, *p*s < .001). Physical properties of negative and neutral images did not significantly differ from one another (all *p*s > .05).

were no significant differences in visual characteristics between valence conditions or counterbalance conditions (see Table 2).

A second set of images, all of which were neutral images of objects, were derived from the Bank of Standardized Stimuli database (BOSS; with permission; Brodeur et al., 2010) and the internet. This second set was developed to be paired with the NAPS images at encoding (see below). Cohort A had a total of 192 neutral images of objects (119 from BOSS, 73 from the internet) and Cohort B had 200 neutral images of objects (124 from BOSS, 76 from the internet).

As one of the goals of this study was to examine the effects of conceptual relatedness, a norming study was conducted to develop a set of image pairs, varying in conceptual relatedness. Each image pair included an image of a negative or neutral scene derived from NAPS and an image of a neutral object from BOSS/internet. In the norming study participants rated the image pairs on a scale of 1 ('Images are not related at all') to 5 ('Images are highly related'; details of the methods and results of this norming study are available in Appendix: Norming Study). The results of the norming study determined the final selection of the image sets described above. For this experiment, each NAPS image had a conceptually related object (Cohort A: $M_{rel} = 3.66$, $SD_{rel} = 0.60$; Cohort B: $M_{rel} = 3.80$, $SD_{rel} = 0.49$) or an unrelated object (Cohort A: $M_{rel} = 1.47$, $SD_{rel} = 0.17$; Cohort B: $M_{rel} = 1.46$, $SD_{rel}= 0.14$) for pairing at encoding.

2.2.3 Memory Assessment

The *encoding phase* was modelled after Anderson et al. (2006). This task was programmed in PsychoPy and administered online via Pavlovia. This task included two different types of events: *modulator* events, wherein participants were shown images that were emotional or neutral, and *test* events, wherein participants were shown neutral images prior to the modulator. This study was a two-by-two design wherein each trial both the conceptual relationship between the test and modulator events (unrelated vs. related) and valence of the modulator events (neutral vs. negative) were manipulated.

Each trial of the encoding phase started with a test event, followed by a modulator event, and ended with a filler task (see Figure 1 for example trial and durations). The test event consisted of the presentation of an image of a neutral object (BOSS/internet), hereafter referred to as the **test image**, which was either related or unrelated to the subsequent modulator event. As an attention check, participants indicated via keyboard commands whether they thought they would remember the test image, pressing Q for 'yes' or W for 'no'.

Participants then viewed the modulator event, which consisted of either a negative or neutral NAPS image, hereafter referred to as the **modulator image,** and were asked to indicate via their mouse how emotionally arousing the image made them feel on a Likert scale from 1 ('Relaxed') to 5 ('Emotionally Aroused'). They then completed the 8-second filler task where they were asked to indicate whether a number on the screen was odd or even via keyboard response to limit emotional carry over between trials. Each trial lasted 23 seconds.

During encoding, those in Cohort A completed a total of 64 trials, where there were 16 trials in each of the four relatedness by valence conditions (i.e., unrelated-neutral, related-neutral, unrelated-negative, related-negative). For example, an unrelated-negative trial would include an unrelated test image and a negative modulator image. To address the potential ceiling effects observed in Cohort A (described below), participants in Cohort B viewed more trials at encoding to allow for more variability in performance. As a result, those in Cohort B viewed a total of 80 trials, with 20 trials in each of the four relatedness by valence conditions.

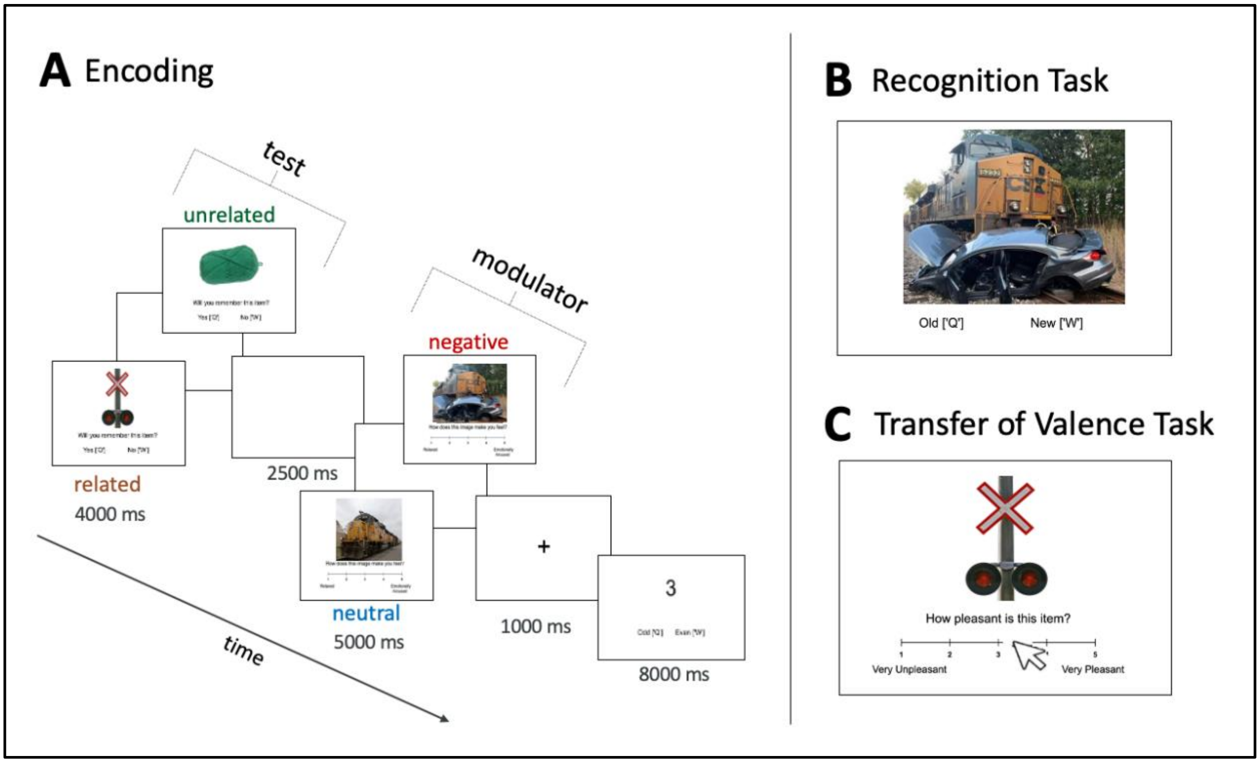

Figure 1.
Experiment task schematic. Illustration of the encoding (A), recognition (B) and transfer of valence (C) tasks. Substitute pictures from the internet are shown for the BOSS and NAPS images to protect the usage of the BOSS and NAPS databases.

The memory *retrieval phase* was also programmed in PsychoPy and was administered online via Pavlovia and consisted of a recognition task. In the recognition task, 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). Individuals were given up to 4 seconds to indicate via keyboard response whether they believed the image on the screen was 'old' or 'new', pressing Q for 'old' and W for 'new'. Each trial was then followed by a 1 second inter-trial interval. There was a 2:1 'old' to 'new' ratio, in line with what was used in Anderson et al. (2006) and the presentation of images was completely randomized. Cohort A viewed 192 images, including the 124 'old' images presented at encoding, alongside 64 'new' foil images (32 objects, 32 scenes (half negative, half neutral)). Cohort B viewed 240 images, including the 160 ‘old’ images viewed at encoding, alongside 80 ‘new’ foil images (40 objects, 40 scenes (half negative, half neutral)).

Each cohort had two counterbalanced versions of the memory assessment. The ‘old’ images viewed at encoding and the ‘new’ foils viewed at retrieval were assigned from each cohort’s respective stimuli set of NAPS, BOSS, and internet images described above. For Cohort A, the 96 NAPS images were randomly assigned to be either old (64) or new (32), with equal numbers of negative and neutral scenes in each. The NAPS images labelled ‘old’ were then randomly assigned to be viewed with either their unrelated (32) or related (32) object pair at encoding in one counterbalance condition, with the inverse being shown in the other counterbalance condition. Consequently, the foils viewed at retrieval consisted of the 32 NAPS images assigned ‘new’ and the object image foils were randomly selected from their respective object pairs (16 unrelated, 16 related).

For Cohort B, the old/new assignment of images were predetermined to allow for an increased number of trials (there were no significant differences in NAPS normative valence, arousal, or visual characteristics for new or old NAPS images; see Table 3). For encoding, the 80 predetermined ‘old’ NAPS images were randomly assigned to be viewed with either their related (40) or unrelated (40) object pair in one counterbalance condition, with the inverse being shown in the other counterbalance condition. The foils viewed at retrieval consisted of the 40 NAPS images predetermined to be ‘new’ and their respective unrelated object pair (40).

Table 3.
Cohort B Old/New NAPS properties

Cohort B

Property	Negative				Neutral			
	Old		New		Old		New	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Valence	2.59**	0.40	2.48**	0.55	5.39**	0.66	5.43**	0.48
Arousal	6.70**	0.47	6.91**	0.59	4.70**	0.42	4.65**	0.37
Luminance	118.60	27.41	118.06	28.25	116.20	33.74	112.92	32.19
Contrast	61.61	11.46	64.58	10.53	63.83	12.46	67.59	11.56
Entropy	7.58	0.35	7.60	0.38	7.52	0.33	7.53	0.37
LAB-L	49.06	11.11	48.78	11.34	47.84	13.47	46.28	12.99
LAB-A	2.30	4.56	3.76	4.73	2.26	4.39	0.06	4.82
LAB-B	6.94	7.02	8.13	13.56	5.77	9.64	5.14	7.88

Note: LAB refers to the CIE L*a*b colour space as described in Table 2. Old and new images were not significantly different in valence, arousal, or physical properties. Negative and neutral images were significantly different in valence and arousal however (as denoted by **, ps < .001). Physical properties of negative and neutral images did not significantly differ from one another (all ps > .05).

2.2.4 Transfer of Valence Task

Although not the primary focus of this study, transfer of valence effects were also assessed to examine whether the retroactive effects of emotion on memory manifest in terms of preference. That is, can emotion retroactively influence the perceived pleasantness of preceding information and is that phenomenon contingent on conceptual relatedness?

The *transfer of valence task* was programmed in PsychoPy and administered online via Pavlovia. In this task, participants were shown the 'old' object images (Cohort A: 64 objects; Cohort B: 80 objects) in a random order and were given up to 4 seconds to rate how pleasant they felt this image was on a Likert scale from 1 ('Not Pleasant') to 5 ('Very Pleasant') Each trial was then followed by a 1 second inter-trial interval.

2.3 Procedure

Participants began by accessing the study online through a link to a Qualtrics survey, where they provided informed consent and completed the health screen. Participants were then directed via a link to the *encoding task* on Pavlovia. Participants began the *encoding task* with a three-trial practice session to allow them to get accustomed to the controls before completing the actual trials. Following the *encoding task*, participants were redirected back to the Qualtrics survey where they were provided the instructions and link to complete the second session the next day.

The second session was conducted between 21 to 28 hours later (average delay in hours, Cohort A: *M* = 24.33, *SD* = 1.56; Cohort B: *M* = 24.47, *SD* = 1.32). This session began with participants completing the CESD-R-20 and the STAI which were administered via Qualtrics. Participants were then directed via a link to the *recognition task* on Pavlovia. Participants completed a three-trial practice session to orient them to the *recognition task* before completing the actual trials. They then completed the *transfer of valence task*, where again they completed a three-trial practice session followed by the actual trials. Upon completion of the *transfer of valence task*, participants were redirected to a Qualtrics survey where they were debriefed on the purpose of the study.

Chapter 3: Results

As noted above, memory was assessed in two independent cohorts. In Cohort A, we observed ceiling effects that possibly precluded us from observing the pre-requisite emotional enhancement effect for modulators (detailed below). Hence, we ran a second Cohort (i.e., Cohort B). Below are the full results for both Cohorts A and B.

3.1 Memory Assessment Data Processing

To measure memory performance on the recognition task participants' responses were categorized 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'). Although it is common to calculate performance as percent correct (hits + correct rejections / number of trials) it is not appropriate if there is a suspected response bias or an unequal number of old and new images at test, as was the case in this study. Some prior literature has found a response bias towards emotional images, in that participants are more likely to have false alarms for new emotional images, (i.e., wrongly identifying an emotional item as 'old'; Kapucu et al., 2008). Thus, in this study I used signal detection theory (SDT; Wixted, 2007) to derive a sensitivity index, d', as our performance measure, as it considers potential response biases. d' takes the z transform of hits minus the z transform of false alarms (i.e., $d' = z(H) - z(F)$).

3.2 Analyses

Two separate 2 by 2 (valence by relatedness) repeated-measures ANOVAs were conducted to examine the separate and combined effects of valence and relatedness on memory performance denoted by d'; one on the modulator images and one on the test images.

3.3 Cohort A

3.3.1 Memory Assessment

Modulator images. When comparing d' scores for modulators across conditions (see Figure 2), unexpectedly, there was no significant effect of valence (F(1,70) = 0.11, p = .74, η_p^2 < 0.01, 95% CI [0.00, 0.06]). There was also no effect of relatedness (F(1,70) = 0.21, p = .65, η_p^2 < 0.01, 95% CI [0.00, 0.08]) and no valence by relatedness interaction (F(1,70) = 0.19, p = .67, η_p^2 < 0.01, 95% CI [0.00, 0.07]). Analysis of decision criteria C, a response bias statistic calculated in SDT, (i.e., C = ½(z(H) + z(F)), indicated that there was a significant response bias towards negative modulators when compared to neutral modulators (t(70) = 4.52, p < .001, d = 0.48, 95% CI [0.33, 0.66]). Accordingly, in Cohort A, we did not observe the expected and pre-requisite emotional enhancement effect, only a propensity to endorse any emotional item as old (bias).

Test images**.** Participants' d' scores for test images (see Figure 2) indicated no significant effect of valence (F(1,70) = 0.003, p = .96, η_p^2 < 0.01, 95% CI [0.00, 0.02]) and no significant relatedness by valence interaction scores (F(1,70) = 2.76, p = .10, η_p^2= 0.04, 95% CI [0.00, 0.16]). There was, however, a significant effect of relatedness (F(1,70) = 41.08, p < .001, η_p^2 = 0.37, 95% CI [0.20, 0.51]) in that test images that were remembered better when they were unrelated versus related to the modulators.

3.3.2 Transfer of Valence Task

To analyze transfer of valence, I analyzed participants' pleasantness ratings for test images via a 2 by 2 (valence by relatedness) repeated measures ANOVA (Figure 3). When analyzing pleasantness ratings for test images it was determined that there was no significant

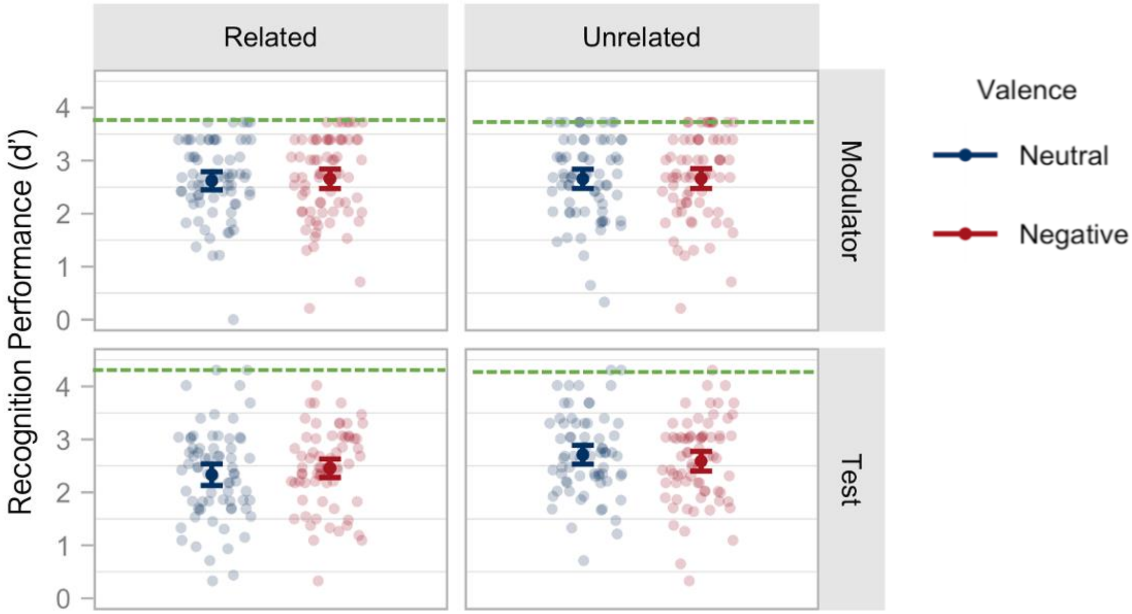

Figure 2.

Cohort A. Recognition performance for modulator and test images via d' scores for each relatedness by valence condition. The green dotted line indicates the maximum d' score possible (max_{mod} = 3.73, max_{test} = 4.31). Maximum d' scores are dependent on the number of possible hit and false alarm trials.

main effect of valence ($F(1,70) = 3.29$, $p = .07$, $\eta_p^2 = 0.04$, 95% CI [0.00, 0.17], however, there was a main effect of relatedness ($F(1,70) = 156.00$, $p < .001$, $\eta_p^2 = 0.69$, 95% CI [0.57, 0.77]) in that test images that preceded an unrelated scene were rated more pleasant than those preceding a related scene. Additionally, there was a marginally significant relatedness by valence interaction ($F(1,70) = 4.00$, $p = .05$, $\eta_p^2 = 0.05$, 95% CI [0.00, 0.18]). Post-hoc analyses were conducted to determine the nature of this interaction. Significance was considered as $p < .025$ as per Bonferroni correction for two comparisons (negative vs. neutral in each relatedness condition). These post-hoc analyses determined that test images preceding negative modulators were rated as less pleasant than those preceding neutral images in the unrelated condition ($t(70) = 3.22$,

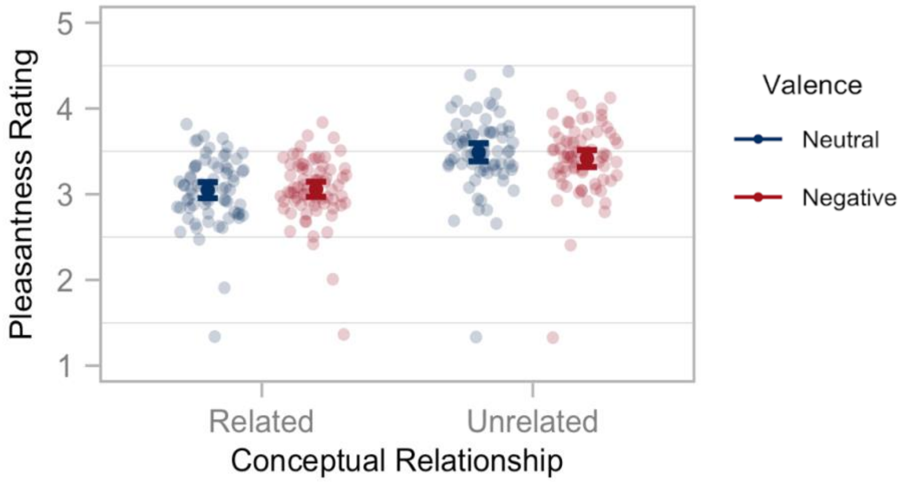

Figure 3.
Cohort A: Average pleasantness ratings for test images viewed at encoding from 1 ('Not Pleasant') to 5 ('Very Pleasant'). Valence denotes the valence of the modulator these test images preceded at encoding.

p = .002, d = 0.38, 95% CI [0.14, 0.64]) but not in the related condition (t(70) = -0.30, p = .76, d = -0.04, 95% CI [-0.26, 0.20]).

To assess whether the observed transfer of valence effects were a function of memory (i.e., participants rating images they remember as being more pleasant), a hits-only analysis was conducted, where only participant's pleasantness ratings for items that participants remembered in the recognition task were analyzed. Here it was observed that the main effects remained the same with a significant main effect of relatedness (F(1,70) = 73.64, p < .001, η_p^2 = 0.51, 95% CI [0.35, 0.63]) and no main effect of valence (F(1,70) = 0.09, p = .92, η_p^2 < 0.01, 95% CI [0.00, 0.03]), however, the interaction was no longer significant (F(1,70) = 2.08, p = .15, η_p^2 = 0.03, 95% CI [0.00, 0.14]). Therefore, when limiting analyses to test images that participants remembered, the valence by relatedness interaction disappeared.

3.3.3 Potential Ceiling Effects

One observation made within Cohort A's memory performance was that the overall accuracy scores (number of hits and correct rejection over the total number of trials) for both modulator and test images were high (M = 0.84, SD = 0.09). Memory performance was particularly high for modulators with participants responding with 100% accuracy for modulators in one of the conditions (e.g., related-negative), in 11% of participants. These high accuracy scores indicate that there may have been ceiling effects that limited our ability to detect differences between conditions, especially in our modulators. To circumvent this issue, trial numbers in Cohort B were increased in an attempt to decrease performance.

3.4 Cohort B

3.4.1 Memory Assessment

***Modulator images*.** When comparing d' scores for modulators (see Figure 4), it was observed that, like in Cohort A, there was no main effect of relatedness ($F(1,81) = 0.16$, $p = .69$, $\eta_p^2 < 0.01$, 95% CI [0.00, 0.06]) as well as no significant valence by relatedness interaction ($F(1,81)= 0.53$, $p = .47$, $\eta_p^2 = 0.01$, 95% CI [0.00, 0.08]). However, unlike Cohort A, there was a significant main effect of valence ($F(1,81) = 5.12$, $p = .03$, $\eta_p^2 = 0.06$, 95% CI [0.00, 0.18] where negative modulators were remembered better than neutral modulators. Thus, in Cohort B, we did observe the expected, prerequisite emotional memory enhancement. Additionally, analyses of decision criteria C in Cohort B indicated that, similar to Cohort A, there was a significant response bias towards negative modulators when compared to neutral modulators ($t(81) = 3.87$, $p < .001$, d = 0.37, 95% CI [0.24, 0.55]).

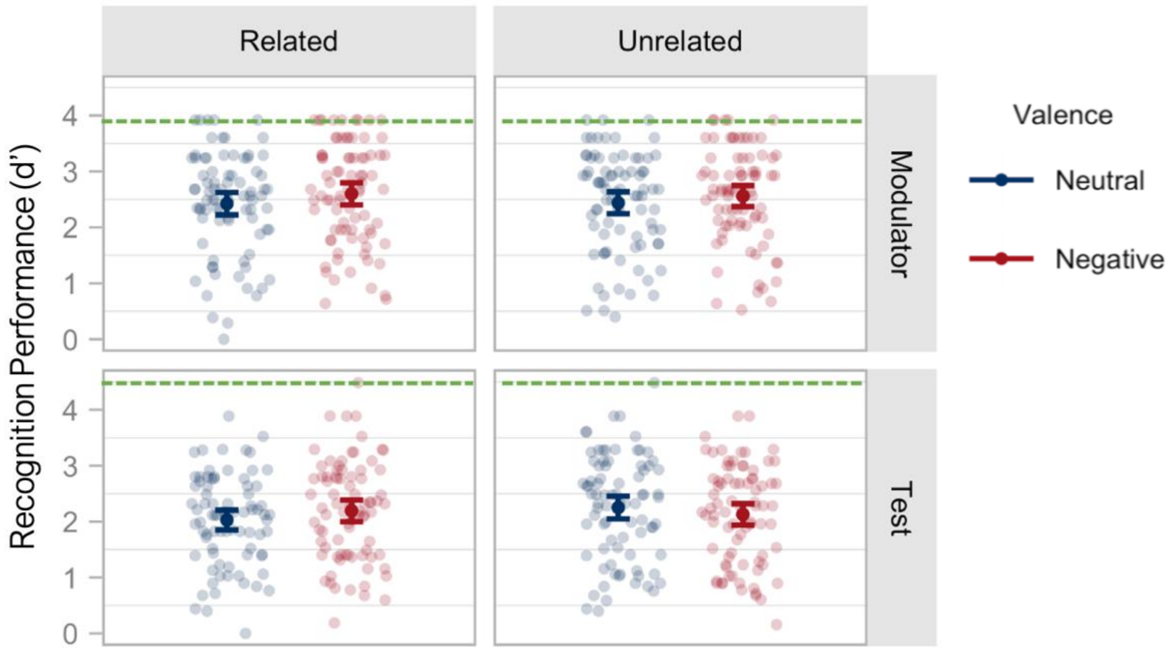

Figure 4.
Cohort B. Recognition performance for modulator and test images via d' scores for each relatedness by valence condition. The green dotted line indicates maximum d' score (max_{mod} = 3.92, max_{test} = 4.48).

Note that the increased trial numbers reduced overall accuracy for Cohort B (M = 0.80, SD = 0.11), and the number of participants who reached 100% accuracy in a modulator condition reduced to 7%.

Test images. For test images (see Figure 4), there was a significant main effect of relatedness ($F(1,81) = 8.74$, $p = .004$, $\eta_p^2 = 0.10$, 95% CI [0.01, 0.23]) where unrelated test images were remembered better than related test images (similar to Cohort A). Also, there was no significant main effect of valence ($F(1,81) = 0.76$, $p = .39$, $\eta_p^2 = 0.01$, 95% CI [0.00, 0.09]). Critically, in Cohort B, there was a significant valence by relatedness interaction ($F(1,81) = 19.83$, $p < .001$, $\eta_p^2 = 0.20$, 95% CI [0.06, 0.34]). Post-hoc analyses were conducted to determine the nature of this interaction. This consisted of two pairwise comparisons, one per relatedness condition. Significance was considered as $p < .025$ as per Bonferroni correction for two comparisons (negative vs. neutral in each relatedness condition). These post-hoc analyses determined that, as expected, in the related condition, test images preceding negative modulators were remembered significantly better than those preceding neutral modulators ($t(81) = 3.60$, $p < .001$, d = 0.40, 95% CI [0.19, 0.62]). However, the opposite was true in the unrelated condition, wherein test images preceding neutral modulators were remembered significantly better than those preceding negative modulators ($t(81) = 2.44$, $p = .02$, d = 0.27, 95% CI [0.04, 0.50]). Thus, these post-hoc analyses elucidated that this was a crossover interaction where the effect of emotion on memory for preceding images was dependent on their conceptual relatedness.[1]

3.4.2 Transfer of Valence

Repeated-measures ANOVA of pleasantness ratings for Cohort B (Figure 5) demonstrated the same pattern of main effects as Cohort A. Specifically that there was no significant main effect of valence ($F(1,81) = 2.26$, $p = .14$, $\eta_p^2 = 0.03$, 95% CI [0.00, 0.13]) and there was a significant main effect of relatedness ($F(1,81) = 113.3$, $p < .001$, $\eta_p^2 = 0.58$, 95% CI [0.45, 0.68]) in that test images that preceded unrelated modulators were rated more pleasant than those preceding related modulators. Similar to Cohort A, there was a significant relatedness

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[1] Additional exploratory pairwise comparisons of memory performance for test images indicated that unrelated images were remembered better than related ones in the neutral condition ($t(81) = 5.44$, $p < .001$, d = 0.60, 95% CI [0.39, 0.84]) but not in the negative condition ($t(81) = -1.38$, $p = .17$, d = -0.15, 95% CI [-0.36, 0.06]).

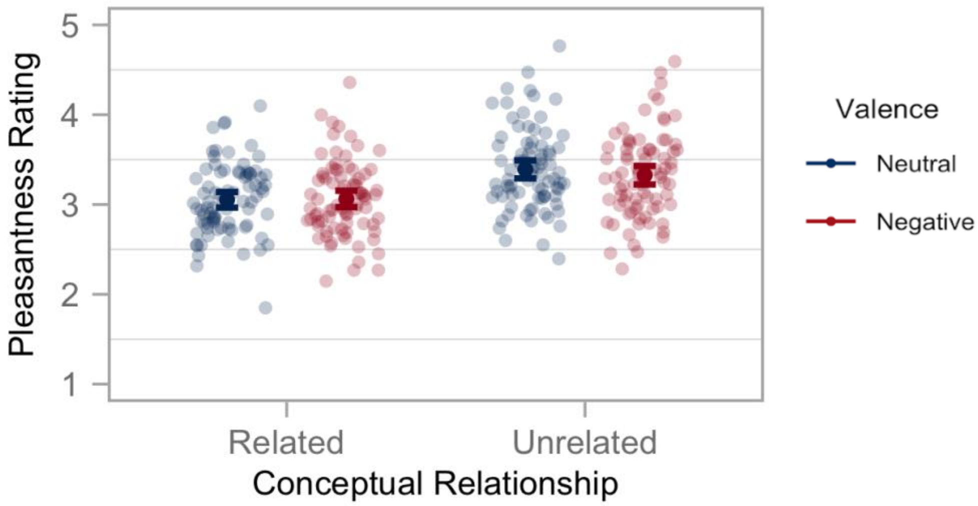

Figure 5.
Cohort B: Average pleasantness ratings for test images viewed at encoding from 1 ('Not Pleasant') to 5 ('Very Pleasant'). Valence denotes the valence of the modulator these test images preceded at encoding.

by valence interaction ($F(1,81) = 4.34$, $p = .04$, $\eta_p^2 = 0.05$, 95% CI [0.00, 0.17]). Post-hoc analyses were conducted and again significance was considered as $p < .025$ as per Bonferroni correction for 2 comparisons (negative vs. neutral in each relatedness condition). These post-hoc analyses determined that, in line with our findings in Cohort A, test images preceding negative modulators were rated as less pleasant than those preceding neutral modulators in the unrelated condition ($t(81) = 2.74$, $p = .01$, d = 0.30, 95% CI [0.06, 0.57]) but not in the related condition ($t(81) = -0.35$, $p = .70$, d = -0.04, 95% CI [-0.24, 0.18]). Thus, as in Cohort A, participants rated test images as more pleasant if they preceded unrelated modulators, especially if the preceding unrelated modulator was neutral.

Similar to Cohort A, to assess whether the observed transfer of valence effects were a function of memory, a hits-only analysis was conducted. Here it was observed that the main effects remained the same, with a significant main effect of relatedness ($F(1,81) = 115.00$, $p < .001$, $\eta_p^2 = 0.59$, 95% CI [0.45, 0.68]) and no main effect of valence ($F(1,81) = 0.84$, $p = .36$, $\eta_p^2 = 0.01$, 95% CI [0.00, 0.09]), however the interaction was no longer significant ($F(1,81) = 1.47$, $p = .23$, $\eta_p^2 = 0.02$, 95% CI [0.00, 0.11]). These effects mirrored Cohort A, in that when limiting analyses to test images that participants remembered, the valence by relatedness interaction disappeared.

Chapter 4: Discussion

4.1 Summary of Findings

The present study aimed to elucidate how conceptual relationships between stimuli influence the retroactive effects of emotion on memory for preceding items. This question was investigated via two cohorts. In Cohort A, I did not observe the expected emotional enhancement effect among modulator images, which may have been the result of potential ceiling effects in memory performance. In Cohort A, there was also a main effect amongst test images where unrelated test images were remembered better than related test images. By contrast, in Cohort B, where we had increased trial numbers to improve measurement sensitivity, there was an observed emotional enhancement for modulator images where negative images were remembered better than neutral images. Also, as in Cohort A, Cohort B demonstrated a main effect of relatedness for test images where unrelated images were remember better than related. Interestingly, when the emotional enhancement modulator effect emerged in Cohort B, so did a valence by relatedness interaction for test images. In support of our hypothesis, it was observed that when the test and modulator images were related, emotion served to enhance memory for the preceding item. Further, when the two images were unrelated, emotion served to impair memory for the preceding item. Importantly, the emergence of the effects observed in Cohort B necessitates a replication sample to ensure these effects are consistent and replicable amongst different samples. Although not included in this thesis, a replication of the findings from Cohort

B is currently underway. Given the potential limitations in Cohort A (i.e., ceiling effects), this discussion will largely focus on the results observed in Cohort B.

4.2 Emotional Enhancements in Memory

Consistent with the emotional memory literature, in Cohort B, an analysis of sensitivity indicated an emotional enhancement of memory effect where negative images were remembered better than neutral ones. This effect has been observed via a variety of memory assessments including recognition (as was used in the present study), free-recall, and recollection (for review see Ack Baraly et al., 2017). The emotional enhancement of memory effect is not always observed, however. In fact, this effect did not occur in Cohort A. As mentioned above, it is speculated this may have been the result of ceiling effects in memory performance.

As described in the introduction, there are many factors that are thought to contribute to the emotional enhancement of memory effect including attentional biases, rehearsal, and bolstered cellular consolidation. The attentional biases result from the bottom-up salience of emotional stimuli, which attracts more attentional processes which facilitate encoding (Talmi et al., 2007). Emotion is also enhanced via post-encoding processes. For instance, research has suggested that individuals are more likely to ruminate about and rehearse emotional experiences which helps to strengthen the memory trace for that event (Finkenauer et al., 1998; Rime et al., 1991). Emotion also acts to bolster cellular consolidation via the release of hormones and activation of NE systems in the amygdala, facilitating the consolidation of long-term emotional memory (see McGaugh, 2004 for a review). These various mechanisms interact to contribute to stronger memory for emotional events.

In the current study, the emotional enhancement of memory effect in the modulators was a prerequisite for us to then investigate the retroactive effects of emotion on memory, accordingly in the next section I discuss those results only in the context of Cohort B.

4.3 Retroactive Effects of Emotion

As described above, there was a significant valence by relatedness interaction for test images, whereby emotion enhanced memory for preceding images that were related, but impaired memory for preceding images that were unrelated. These findings are consistent with the arousal-biased competition (ABC) model (Mather & Sutherland, 2011), which posits that arousal modulates the strength of mental representations for competing stimuli, selectively enhancing the mental representations of stimuli that are deemed high priority while suppressing those deemed low priority. When an image is considered high priority, individuals allocate their cognitive resources (i.e., attention, working memory, etc.) toward processing that information at encoding as well as prioritizing strengthening the mental representation during consolidation. Priority can be indicated via bottom-up processes such as perceptual salience, emotional salience, or top-down processes such as conceptual relatedness, as was done in our study. Thus, the results of our study fall in line with what would be predicted with the ABC model, with high-priority (conceptually related) preceding stimuli being selectively enhanced in memory when it precedes emotional material and low priority (conceptually unrelated) being impaired. The GANE model (Mather et al., 2016a) described in the introduction is the neurobiological instantiation of the ABC model and provides insight into the neural mechanisms that underlie these effects.

It is considered adaptive to remember neutral events surrounding an emotional experience as we learn they may be indicative of threat in future situations (Knight & Mather, 2009; Nairne et al., 2007; Sakaki et al., 2014). In the GANE model, when emotional arousal is induced while a mental representation of preceding information is still active, it can strengthen or weaken this representation depending on the perceived priority of the preceding information via local NE-glutamate interactions. If the information is deemed high priority, the mental representation is strengthened, alternatively, if it is deemed low priority it is weakened, as observed in the current study. This enhancement for high-priority items is an adaptive function that allows more efficient encoding and storage of important information, which is increasingly relevant in situations that are arousing or threatening (Clewett et al., 2018). As indicated above, the modulating effects of priority are mediated by the LC, a brainstem region which many have attributed to the processing of motivationally significant stimuli (Aston-Jones et al., 1999; Berridge & Waterhouse, 2003). Recent work by Clewett et al. (2018) has elucidated the role of the LC in the GANE model. In this study, they observed that, in line with the GANE model, threat-induced arousal increased the effects of top-down priority on memory, with goal-relevant stimuli being selectively enhanced in memory. Most importantly, they observed that under arousing conditions, LC activity was associated with more selective and localized neuronal processing and this selectivity was predicted to contribute to the observed enhancements for high-priority information. The importance of the LC in scene encoding was further demonstrated via a whole-brain analysis that revealed that arousal modulated encoding activity only in the LC and parahippocampus (a region important for scene processing) and nowhere else.

An important consideration, however, is that the GANE model explains how priority influences memory when memory is tested immediately as it touches on the immediate neural processes during encoding and early consolidation. Yet, the present study included a 24-hour delay between encoding and test, which leaves ample time for additional consolidation mechanisms to contribute to these results beyond GANE. Other studies that have observed post-encoding emotion memory enhancements after a longer delay (1 week) have highlighted noradrenergic activity in the amygdala as being a predominant contributor to these enhancements in memory (see Anderson et al., 2006; Knight & Mather, 2009 for discussion).

The GANE model, however, does not exist independent of long-term consolidation mechanisms. One model that may complement the GANE model is the *tag-and-capture model* (Redondo & Morris, 2011). The tag-and-capture model highlights that some memory traces are tagged during encoding to be captured later during periods of greater plasticity to facilitate long-term consolidation. The amygdala acts to tag information that is identified as high priority via bottom-up or top-down processes, such as emotional or goal-relevant information, for later retrieval (for review see Ack Baraly et al., 2017). Arousal (i.e., emotional arousal) at the time of encoding, induces tonic increases in dopaminergic activity, which help to facilitate the later stages of consolidation and explains why in some instances, enhancements are only observed after a delay (Redondo & Morris, 2011). In reference to the GANE model, Mather et al. (2016b) argue that NE levels in NE hotspots stimulate NMDA and β-adrenergic activity which are responsible for tagging stimuli for later consolidation (Moncada et al. 2011). This would allow high-priority items to be further amplified via long-term consolidation mechanisms which could be contributing to our findings after a delay; however, further research using memory testing both immediately and after a delay is required to support this theory.

In the real world, memories are encoded as an unfolding series of events, which are temporally, and often conceptually, connected. Although temporal memory was not assessed in this study, other work has suggested that emotional arousal enhances temporal order memory for related events (Schmidt et al., 2011) and thus complements our findings. The temporal binding of sequentially encoded related events may lead to a predictive model of how the experience unfolded, with perceived causal links between events (Palombo & Cocquyt, 2020). In our study this would be the temporal binding between our test and modulator images, where conceptually related items preceding a negative event would acquire the most biologically relevant predictive utility, bolstering them in memory as was observed in our study (Palombo & Cocquyt, 2020; for similar discussion see Clewett et al., 2019). Therefore, although not directly assessed, temporal memory binding may be a contributing factor to the effects observed in our study.

4.4 Retroactive Effects of Conceptual Relatedness

Prior work suggests that semantic associations between sequentially presented words at encoding can improve memory for the latter, in a process referred to as semantic priming (McNamara, 2005). This is thought to result from a spreading of activation effect that occurs when an item is presented that prepares the brain to process/encode related information (Collins & Loftus, 1975). Beyond aiding in the initial encoding of information, this spreading of activation effect can facilitate memory retrieval via free-recall, with each recalled term acting as a cue for the next (Howard & Kahana, 2002). However, in this study I was interested in the retroactive influence of semantic associations, assessing memory for the prime itself. As noted, in this study there was a main effect of relatedness where unrelated test images were remembered better than related ones. Although this was an unexpected finding, I propose that this finding can be understood via *prediction error.* Prediction error is the extent to which prior expectations deviate from current observations (Rescorla & Wagner, 1972). In the field of memory, prediction error has been shown to impact explicit memory with high prediction error bolstering memory (Bar, 2007; Greve et al., 2017). Prediction error is lowest when events are semantically or conceptually congruent (Bar, 2007), thus, the unrelated trials in this study could have resulted in higher prediction error than related trials. In turn, memory for unrelated test images was enhanced. Our present findings are consistent with the results of a previous study where prediction errors retroactively enhanced memory for preceding events, independent of arousal (Kalbe & Schwabe, 2020). These findings help to embed our study into the current research on the implications of expectation and congruence on memory.

4.5 Strengths, limitations, and future directions

The work presented here makes meaningful contributions to our understanding of how emotion can both retroactively enhance and impair memory for neutral items. This study was the first to use sequentially presented image pairs to investigate the direct effects of conceptual relationships on the retroactive effects of emotion on memory. Heavily influenced by the theoretical underpinnings of the ABC and GANE models, this study better elucidates how we can retroactively dictate priority via conceptual relatedness.

One drawback of the present study was that the online administration of the study limited the data that was able to be collected. A major concern for online studies is respondent fatigue, where participants become bored of the task at hand and the quality of their data declines. This is especially troublesome in an online environment, where increased risk of distraction and lack of supervision results in a relatively uncontrolled experimental environment. For this reason, in the present study special care was taken to ensure each session did not surpass 1 hour. To accomplish this, I opted not to collect confidence ratings from our recognition task, where participants would have indicated their confidence in their “old/new” selection. This measure would have given us the means to distinguish between different types of recognition memory, such as familiarity and recollection (Yonelinas, 1994). Familiarity is the feeling of knowing that an item is ‘old’ without conscious retrieval of the prior presentation, whereas recollection demonstrates a richer form of recognition where one can consciously retrieve details of the encoding event (Gardiner, 1988; Yonelinas, 1994). Although distinguishing between retrograde effects on familiarity vs. recollections was not the primary research question, these measures would have provided insight on the quality or richness of the memory.

A relevant consideration when observing an emotional enhancement in memory, as observed in our modulator analysis, are the potential influences of semantic inter-relatedness of negative stimuli. Prior work suggests that negative stimuli are inherently higher in semantic relatedness than which contributes to them being better remembered (Talmi & Moscovitch, 2004). Early work has demonstrated that semantically related stimuli are more likely to be remembered than unrelated stimuli (Mathew & Waring, 1972), an effect which is further amplified by arousal (Buchanan et al., 2006). These increased semantic relationships among negative stimuli can contribute to response biases towards negative material, as observed in both cohorts. Semantic relationships between emotional items can foster a false sense of familiarity at retrieval which leads to individuals being more likely to wrongly endorse a negative image as having been presented at encoding than a neutral image (Bennion et al., 2013; Dougal & Rotello, 2007).

In the present study, substantial effort was made to ensure the images chosen to induce negative emotional arousal were selected from a variety of categories (e.g., dirty dishes, car accident, deceased animal, etc.), however, the commonality of them being *negative* could have could have inadvertently led to them being considered related. It is important to note, however, that the influence of semantic relationships on the emotional enhancement of memory effect is less substantial for visual stimuli (Talmi et al., 2007b). This is thought to be due to emotional images being more distinctive (Talmi et al., 2007a; Talmi & MacGarry, 2012) and attentionally demanding (Kensinger & Corkin, 2004; Talmi et al., 2007b; Talmi & MacGarry, 2012) than emotional words, thus they have more factors contributing to their enhancement in memory beyond semantic inter-relatedness. Accordingly, although they likely do not tell the whole story, it is important to acknowledge the potential influences of semantic relationships between emotional stimuli on the observed emotional enhancements in memory.

A future study that would further elucidate the cognitive mechanisms that underlie this effect, would be to distinguish between conceptually related test images that have a causal link to the following scene and those that do not. For example, an image of a dog bed followed by an image dog has a clear conceptual relationship, but it’s not necessarily causal. Alternatively, a picture of a match followed by an image of a campfire can be considered both conceptually and causally linked. Investigating this distinction would allow us to determine whether broad conceptual links are sufficient to be retroactively deemed high priority or if they need to be perceived to have caused the emotional event. Potentially those with a causal link would be further bolstered in memory due to their greater perceived predictive utility.

Additionally, as highlighted above, the present study may employ neural mechanisms from both the GANE and tag-and-capture models (Mather et al., 2016b). To better understand the observed effects, it would be beneficial to conduct this study with both an immediate and delay testing condition. This would allow us to discern whether the observed effects can be accounted for by the immediate mechanisms of GANE, longer-term consolidation mechanisms, or a combination of the two.

4.6 Final Remarks

In sum, the present study offered unique and novel insight into the influence of conceptual relationships on the retroactive effects of emotion on memory. Although in need of replication, these findings demonstrate conceptual relevance as an effective method of retroactively dictating priority. These findings allow us to understand why certain details surrounding a real-world emotional event may be remembered better than others. This research may have implications in eye-witness testimony, to aid in our understanding of why some details of an event may be remembered while others are forgotten. For example, an individual who witnessed a bank robbery may remember seeing a ski mask on the steps before walking into an active robbery, however, they seem to not remember seeing the shoe that was next to it. Certain neutral details encountered before an emotional event, such as the ski mask, may be reliably recalled if they are perceived to be related to the event, for example, perhaps the witness makes the connection that bank robbers had brought the mask to conceal their identities. Memory for the shoe, however, may be impaired because it is retroactively deemed to be irrelevant to the bank robbery. It is critical to understand why stimuli may be omitted from an eye-witness's testimony, as this may not be a sign of deceit, rather a sign of adaptive selectivity in memory (Brown, 2003).

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Appendix

Norming Study

Before we investigate how semantic relatedness affects emotional retrospective memory, we conducted a norming study to gather normative ratings for the selected stimuli. Ratings of emotional arousal of the modulator images were collected to ensure that the arousal of the negative and neutral stimuli were significantly different from each other. Most importantly, ratings of semantic relatedness between modulator and test image pairs were collected to establish that the conceptually related and conceptually unrelated groups were significantly different from each other.

Participants

Participants in this experiment were sampled from the same population as the previous experiments and recruited through the HSP Sona System. The final sample (after exclusions) consisted of 29 undergraduate students (M_{age} = 20.14, SD_{age} = 1.43; 19 female, 10 male). A total of 12 participants were excluded from the final sample. Of those excluded, eight were excluded because they completed fewer than 50% of the trials, and four were excluded because their trial-wise differences (TWD) for relatedness ratings were greater than our exclusion threshold. The threshold was set to exclude any participants with a TWD of less than 1% for more than 35% of trials. This was set as a threshold as a way to detect and exclude participants who may have been repeatedly clicking the same response on every trial, without honestly considering the respective task. Additionally, all participants were fluent in English and between 18-35 years old. Participants were granted one course credit in exchange for their participation.

Materials and Stimuli

This study was administered online through Qualtrics, which hosted the questionnaires, and Pavlovia, which hosted the norming task. Participants completed the same questionnaires as the previous studies: a general demographics survey, the CES-D, and the STAI. The norming task was programmed using PsychoPy v3.0, and the finalized version of the task was uploaded onto Pavlovia. Participants were provided with links to direct them to the respective Qualtrics survey and Pavlovia task.

The selected stimuli were comparable to the previous studies: modulator images consisted of 128 images chosen from the NAPS image database. Among these images, 64 were negative and 64 were neutral. Additionally, 256 test images were selected from the BOSS image database and Google Images. Among the test images, half were chosen for being conceptually related to the modulator images, and half were chosen for being conceptually unrelated to the modulator images. Conceptual relatedness between image pairs was determined based on a norming process within the lab. A group of lab members were individually provided with a list of the chosen NAPS images and were each instructed to think of objects that were intuitively the most conceptually related to the respective scene. Next, images corresponding to the listed objects were selected, primarily from the BOSS database, and supplemented from Google Images. After this, an additional group of lab members reviewed these lists and subjectively selected the most conceptually related pairs for each modulator image. The finalized conceptually related test images were selected for possessing the greatest agreement from lab members where possible. A matched number of conceptually unrelated test images were selected for each modulator image as well.

Procedure

Upon signing up for the study on the HSP website, participants were provided with a link to the survey on Qualtrics. Prior to commencing the survey, all participants were provided with a consent form, and agreed to participate in the study. The survey consisted of the general demographic questionnaire, followed by the CES-D and the STAI. Next, participants were randomly assigned one of two links to the norming task on Pavlovia. The link determined which counterbalance condition they were assigned.

The norming portion was administered in two successive parts. In the first part, a series of NAPS images were presented, and participants were instructed to rate the emotional arousal of each image (see Figure 3.1). Each image was presented until participants responded using a slider scale located below the image. The slider scale ranged from 1, "Relaxed", to 5, "Emotionally Aroused". In total, there were 128 trials, and each trial was separated by a one second ITI with a crosshair. For the second part of the norming task, participants were presented with a series of two side-by-side images and asked to rate how related the two images were (see Figure 3.2). The test images were located on the left, and the modulator images were located on the right. Below the stimuli, participants indicated their ratings using a slider scale ranging from 1, "Not Related" to 5, "Very Related". Similar to the first part of the study, there were 128 trials which were each separated by a one second ITI with crosshair. Additionally, each trial was presented until participants indicated their response using the slider scale. Once the norming task was complete, participants were instructed to return to the initial Qualtrics survey where they were provided with a debrief sheet which informed them about the nature of the study.

Results & Discussion

This norming study collected normative ratings for a total of 128 modulator images and their respective test image pairs. Based on these ratings, we created our final stimuli set, which consists of 96 image pairs. Among these images, there are 24 pairs in each category: related negative, related neutral, unrelated negative, and unrelated neutral. The NAPS images in this stimuli set were balanced based on a number of visual characteristics, to ensure that the negative and neutral groups did not significantly differ from each other in this regard (see Table A.1). Inclusion criteria for the stimuli set was based on ratings of both arousal and conceptual relatedness. All ratings were given on a scale of one to five. In terms of arousal, a rating of one indicated low arousal, and a rating of five indicated high arousal. Every neutral item had an average of rating of 3.00 or below, and every negative item had an average rating of 3.01 or higher. Six images did not meet this criterion and were excluded accordingly. For conceptual relatedness, a low score indicated that the images were conceptually unrelated, and a high score indicated that they were conceptually related. All unrelated pairs had an average rating below 1.90, and all related pairs had an average rating of above 2.35. Accordingly, 19 image pairs were excluded for having a relatedness score in their unrelated pair > 1.90, and/or a relatedness score in their related pair of < 2.35. An additional seven images were excluded for balancing purposes, to ensure that the negative and neutral conditions did not significantly differ in conceptual relatedness.

Emotional Arousal. A paired-samples t-test of the arousal ratings indicates that the images in the negative group (M = 3.82, SD = 0.43) are significantly more arousing than the images in the neutral group (M = 2.17, SD = 0.33; $t(47) = 20.95$, $p < 0.01$). These results are important because they signify that our negative and neutral conditions strongly differ from each

Table A.1
Norming Study NAPS properties

Norming Study

Property	Negative		Neutral	
	Mean	SD	Mean	SD
Valence	2.52**	0.45	5.39**	0.61
Arousal	6.78**	0.52	4.66**	0.41
Luminance	120.37	28.50	118.51	32.29
Contrast	62.21	11.18	65.39	12.65
Entropy	7.56	0.38	7.54	0.31
LAB-L	49.77	11.55	48.71	12.86
LAB-A	2.81	4.77	2.03	4.15
LAB-B	7.50	9.82	4.88	9.27

Note: LAB refers to the CIE L*a*b colour space as described in Table 2. Old and new images were not significantly different in valence, arousal, or physical properties. Negative and neutral images were significantly different in valence and arousal however (as denoted by **, *p*s < .001). Physical properties of negative and neutral images did not significantly differ from one another (all *p*s > .05).

other in emotionality, which ensures that we have a strong manipulation of emotional arousal. These stimuli will be used as the modulator images in our subsequent study.

Conceptual Relatedness. Several independent samples t-tests were conducted to analyze the results of the ratings of conceptual relatedness. First, the image pairs categorized as conceptually related were, as expected, significantly higher in conceptual relatedness ($M = 3.66$, $SD = 0.60$), compared to the conceptually unrelated image pairs ($M = 1.47$, $SD = 0.17$; $t(110) = 34.39$, $p < .001$). The high t-test statistic demonstrates that there is a high magnitude of difference between the conceptually related and conceptually unrelated image pairs, which is important for our manipulation of conceptual relatedness. A greater magnitude of difference will increase our ability to detect a modulatory effect of conceptual relatedness in subsequent studies, if one exists.

T-tests assessing conceptual relatedness were also conducted separately on both the negative and neutral group, to ensure that this effect still holds in each group. Within the negative condition, image pairs categorized as conceptually related were significantly higher in conceptual relatedness (*M* = 3.60, *SD* = 0.65) compared to the conceptually unrelated image pairs (*M* = 1.45, *SD* = 0.16; *t*(53) = 22.13, p < .001). Similarly, for the neutral condition, conceptually related pairs were significantly higher in conceptual relatedness (*M* = 3.72, *SD* = 0.54) compared to the conceptually unrelated image pairs (*M* = 1.50, *SD* = 0.17; *t*(57) = 27.13, *p* < .001). Analyzing these groups separately is important because it ensures that the differences in conceptual relatedness holds in both negative and neutral conditions. In other words, both the negative and neutral conditions have effective manipulations of conceptual relatedness.

Next, we found that the conceptual relatedness of the negative condition (*M* = 2.52, SD = 1.18) does not significantly differ from the conceptual relatedness of the neutral condition (*M* = 2.61, *SD* = 1.19; *t*(190) = -0.50, *p* = 0.615). This is important because we want to ensure that any observed memory differences between emotional conditions are not due to differences in conceptual relatedness between emotional conditions. Specifically, Talmi & Moscovitch (2004) have acknowledged that emotional stimuli tend to be more semantically related to each other, compared to neutral stimuli. This imbalance in semantic relatedness is problematic because it may confound results, making it difficult to distinguish whether an emotion-induced memory enhancement is truly attributable to the emotionality of the condition, or because the emotional condition is benefiting from the effects of high semantic relatedness. Without norming the emotional conditions on semantic relatedness, it is impossible to know what exactly is producing the memory enhancement (or impairment).

The final analyses we ran were to measure the emotionality of the related and unrelated groups separately. Among the conceptually related group, the negative images (M = 3.60, SD = 0.65) did not significantly differ from the neutral images (M = 3.72, SD = 0.54) in terms of conceptual relatedness ($t(91) = -1.02$, $p = 0.311$). Likewise, among the conceptually unrelated group, the relatedness of the negative images (M = 1.45, SD = 0.16) did not significantly differ from the relatedness of the neutral images (M = 1.50, SD = 0.17; $t(93) = -1.39$, $p = 0.167$). Similar to the previous results, these findings are important because they indicate that the conceptual relatedness between the negative and neutral images, in both the related and unrelated groups, do not significantly differ. In other words, differences in memory for negative and neutral conditions in studies using these stimuli will not be attributable to differences in conceptual relatedness within the conceptually related and unrelated groups.