Recall dynamics reveal the retrieval of emotional context

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Abstract

Memory is often better for emotional than neutral stimuli. An open question is whether the benefit for emotional items can be explained by an associative mechanism whereby items are associated to a slowly updating context. Through this process, emotional features would be integrated with context during study, and would be reactivated during test. The presence of emotion in context would both provide a stronger retrieval cue, enhancing memory of emotional items, as well as lead to emotional clustering, whereby emotionally similar items are recalled consecutively. To measure whether associative mechanisms can explain the enhancement for emotional items, we conducted a free recall study in which most items were emotionally neutral to minimize effects of mood induction and to more closely reflect naturalistic settings. We found that emotional items were significantly more likely to be recalled than neutral items and that participants were more likely to transition between emotional items rather than between emotional and neutral items. Together, these results suggest that contextual encoding and retrieval mechanisms may drive the benefit for emotional items both within and outside the laboratory.

Introduction

Both the emotional quality of an item and the emotional state of an individual can impact how an item is remembered. Emotional items are typically better remembered than neutral items (Dolcos et al., 2004; LaBar & Cabeza, 2006; Kuhbandner & Pekrun, 2013) and emotional states, often created through mood induction, can enhance memory for both neutral and emotional items (Bower, 1981; Eich, 1995; Maratos & Rugg, 2001; Erk et al., 2003). The associative network theory of emotion (Bower, 1981) suggests that emotional information is associated with concurrently presented stimuli and is part of the retrieval cue. This theory has been applied to explain the benefit for items presented in emotional states; however, if emotion enters into such associations, then the effects should extend beyond the "macro" scale of list or experiment level mood effects and be present on the "micro" scale of individual items. Despite this, associative network theory has not been extended to explain the benefit for individual emotional items in neutral contexts. Additionally, there is conflicting evidence as to whether emotion enhances (Doerksen & Shimamura, 2001) or impairs (Kensinger, 2009; Maddock & Frein, 2009) associative memory.

Enhanced memory for items presented during a specific mood may be driven by associations between items and context (Bower, 1981; Lewis & Critchley, 2003). The term context is used here to describe a mental representation which reflects both the external stimuli often considered context, e.g. the color of the computer screen, the experiment room, as well as the internal state of the individual, including their mood and associations automatically retrieved in response to external stimuli. The inclusion of emotion in context can provide a cue for retrieving neutral items associated with the same emotional context during encoding (mood dependent memory effect) or for retrieving emotional items that match the current emotional context (mood congruent memory effect). A natural extension of this mechanism is that individual emotional items should impart their emotional features to context. This emotional information should then be present in the retrieval cue and lead to enhanced memory for emotional items.

Alternatively, the salience theory suggests that enhanced memory for emotional items is the result of more resources dedicated to processing emotional items. Neuro-imaging evidence has shown that emotional items recruit attentional and motivational networks (Dolcos et al., 2004; Kissler et al., 2006; Liu et al., 2012), potentially due to modulatory signals from the amygdala. This modulation hypothesis suggests that the amygdala enhances processing of emotional stimuli in other brain networks (Anderson & Phelps, 2001; Pessoa & Adolphs, 2010). Consistent with this theory, increased amygdala activation correlates with better memory specifically for emotional, but not neutral, items (Canli et al., 2000).

Both salience and context theories derive support from experiments using many emotional stimuli and although this design provides ample statistical power, it does not mirror natural encounters with emotional stimuli and could induce explicit strategy use or mood induction, both of which may interfere with typical organizational tendencies. The goal of our study was to investigate memory for emotional items in a largely neutral context by using a small proportion of emotional relative to neutral items. If with such a design memory is still enhanced for emotional relative to neutral items, this enhancement could be explained by two alternative hypotheses. If emotional items activate emotion features in context during study, and those features are reactivated during retrieval, then this reactivation of emotional features should cue retrieval of emotional items. Specifically, recall of an emotional item should be followed by consecutive recall of other emotional items, since they have similar contexts as the result of their shared emotional features. Such an "emotional" clustering effect falls naturally out of retrieved context theories (Howard & Kahana, 2002) and is in line with other clustering phenomena whereby individuals organize their memories by semantic, episodic and spatial associations (Bousfield, 1953; Kahana, 1996; Miller et al., 2013). Although a previous study on the organization of emotional memories suggests that emotional clustering only occurs when participants are explicitly oriented to the emotionality of items (Siddiqui & Unsworth, 2011), the use of many emotional items may have altered participants' strategies and interfered with a slowly updating context mechanism. Alternatively, if emotional features are not represented in context, then there should be no consecutive recall of emotional items. Instead, the benefit for emotional items may be due to increased attentional processing which does not necessarily lead to emotional clustering.

To assess the interaction of emotion and context, we measured memory success for emotional and neutral items in a free recall task. In free recall, participants study and recall a list of items with no external cues, and thus must rely on contextual information to generate cues. To quantify emotion, we conducted an independent experiment in which a separate group of participants rated each word for emotional valence. The words had originally been selected to be predominantly neutral and there was no emotion-related orienting task. We measured both memory for emotional and neutral items, as well as the tendency of participants to consecutively recall items of similar valence.

Norming study

Methods

We conducted a norming experiment using Amazon's Mechanical Turk (MTurk, Mason & Suri, 2012). MTurk is a crowdsourcing webite used for the mass collection of data via the internet. The

Institutional Review Board at the University of Pennsylvania approved our research protocol, and informed consent was obtained from all participants. The norming study consisted of two parts, a qualifier test to screen for high-performing participants, and the main study in which participants normed the free recall study word pool.

247 participants completed the qualifier study in which they rated the emotional valence of 100 words drawn from the Affective Norms for English Words (ANEW) dataset (Bradley & Lang, 1999). None of these words appeared in the free recall study. Participants were asked to rate words on an emotional sliding scale ranging from unpleasant to pleasant. Though not shown to the participants, these ratings corresponded to a numerical value from 1 to 9, with 1 being unpleasant and 9 being pleasant. The instructions and scale were identical to those used in the ANEW study. Each of the 100 words was presented twice and in a random order to measure internal consistency. Participants were compensated $0.30 for completing the qualifier survey.

Qualification for the main study was determined through internal consistency, external consistency, and response distribution. Internal consistency was measured using the correlation between an individual participant's ratings of the first and second presentations of the same word. External consistency was measured using the correlation between a participant's average rating of a word and the ANEW ratings. To qualify, both internal and external values had to exceed .7 (Cicchetti, 1994). Additionally, participants were required utilize the full range of responses (1-9). 173 participants qualified for the main study.

120 participants completed the main study in which they rated the emotional valence of 1638 words from the free recall study (see below). The rating procedures were identical to the qualifier task and participants were compensated $15. Twenty participants did not rate all words and were therefore excluded from further analysis. Ratings were averaged across the 100 participants who completed the study and each word was then assigned a status of negative (ratings 1-4), neutral (ratings 4-6), or positive (ratings 6-9) valence (Baran et al., 2012).

Results and Discussion

Of the 1638 words, 140 were negative (9%), 1073 were neutral (65%), and 425 were positive (26%). There is evidence that word properties, including word frequency, imageability, concreteness, and semantic relatedness can influence memory performance and vary as a function of valence (Glanzer & Adams, 1990; Talmi & Moscovitch, 2004; Bennion et al., 2013). Therefore, we attempted to simultaneously control for these factors across our three valence categories.

We matched average word frequency between positive and neutral words, and negative and neutral words. We calculated which word pool (either positive or neutral, or negative or neutral) had the higher average word frequency. We then removed from this pool the word with the highest frequency. We repeated this procedure iteratively until the word pools did not significantly differ in word frequency using an unpaired t-test (the p value had to exceed 0.10 to be considered non-significant). Using this new word pool, we then controlled for imageability, concreteness, and semantic relatedness using the same procedure. Imageability and concreteness ratings were only available for 984 of the 1638 words (Wilson, 1988). Semantic relatedness was measured using average word association space (WAS) values (Steyvers et al., 2004). The distributions of semantic relatedness values were compared across word pools and were not reliably different (see Supplemental Information). It is important to note that we matched each valence pool (negative, positive) to the neutral pool. It was impossible to directly match negative and positive pools and still have sufficient words for analysis. Additionally, although we collected arousal data (see Supplemental Information) and found that negative items had higher arousal, on average, than positive items, we could not simultaneously control for all factors and still retain a sufficient number of words for analysis.

After applying the exclusion criteria, 1268 words were available for the free recall analyses, 66 negative (5%), 981 neutral (77%) and 221 positive (17%).

Recently published valence ratings are available for 1555 of our 1638 words (Warriner et al., 2013). We used this dataset to test the reliability of our ratings. We found that though their valence ratings were slightly more positive ($t(3191) = 2.5$, $p = .01$), both ratings were significantly positively correlated ($rho = .9$, $p < .0001$). We used our ratings for the free recall study as values were available for all 1638 words.

Free recall study

Methods

152 (86 female) paid volunteers (ages 18 - 29) were recruited via fliers posted around the University of Pennsylvania campus. Participants were provided with a base monetary compensation plus an additional performance-based monetary incentive to ensure full effort. The Institutional Review Board at the University of Pennsylvania approved our research protocol, and informed consent was obtained from all participants.

Experimental Paradigm

The data reported in this manuscript were collected as part the Penn Electrophysiology of Encoding and Retrieval Study (PEERS), involving three multi-session experiments that were sequentially administered. The data reported below come from participants who completed all three experiments. Additional methodological details can be found in the supplemental information.

Experiment 1 Participants performed an immediate free recall experiment consisting of seven sessions of 16 lists of 16 words presented one at a time on a computer screen. Each word was drawn from a pool of 1638 words taken from the University of South Florida free association norms (Nelson et al., 2004, available at http://memory.psych.upenn.edu/wordpools/PEERS_wordpool.zip). Semantic relatedness was determined using the WAS model (Steyvers et al., 2004). WAS similarity values were used to group words into four similarity bins (high similarity, $\cos\theta > 0.7$; medium-high, $0.4 > \cos\theta < 0.7$; medium-low, $0.14 > \cos\theta < 0.4$; low similarity, $\cos\theta < 0.14$). Two pairs of items from each of the four groups were arranged such that one pair occurred at adjacent serial positions and the other pair was separated by at least two other items. All randomly generated word lists conformed to this structure. The same word was not repeated in a session.

Words were presented concurrently either with a task cue, indicating the judgment that the participant should make for that word, or with no encoding task. The two encoding tasks were a size judgment ("Will this item fit into a shoebox?) and an animacy judgment ("Does this word refer to something living or not living?), and the current task was indicated by the color and typeface of the presented item. There were four no-task lists (participants did not have to perform judgments with the presented items), six single-task lists (all items were presented with the same task, three of each task), and six task-shift lists (items were presented with either task). List and task order were counterbalanced across sessions and participants.

For each list, there was a 1500ms delay before the first word appeared on the screen. Each item was on the screen for 3000ms, followed by jittered 800 to 1200ms interstimulus interval (uniform distribution). If the word was associated with a task, participants indicated their response via a keypress. After the last item in the list, there was a 1200 to 1400ms jittered delay, after which a tone sounded, a row of asterisks appeared, and the participant was given 75s to attempt to recall any of the just-presented items.

Experiment 2 Experiment 2 was identical to Experiment 1 except as described below. There were either 7 (N = 92) or 9 (N = 60) experimental sessions of 12 study lists of 16 words. Experiment 2 included a mix of immediate recall lists, delayed recall lists (the final word was followed by a distractor), and continual distractor lists (each word was followed by a distractor). Distractor tasks consisted of answering math problems of the form $A + B + C = ?$, where A, B, and C were positive, single-digit integers, and participants typed the sum as quickly as possible. Participants performed free recall with five possible time durations for the between-item and end-of-list distractor tasks. As listed here, the first number indicates the between-list distractor duration and the second number indicates the end-of-list distractor duration, both in seconds: 0-0 for immediate (identical to Experiment 1), 0-8 or 0-16 for delayed, and 8-8 or 16-16 for continual distractor recall.

Experiment 3 For 92 participants, Experiment 3 used the externalized recall (ER) procedure (Zaromb et al., 2006) to measure participants' tendency to commit intrusions during recall. Participants were instructed to say aloud every time a specific, salient word came to mind while performing free recall and to press the spacebar immediately following recall of an intrusion or repetition. Participants performed 6 experimental sessions with methods identical to Experiment 1 with ER-specific instructions. For the remaining 60 participants, Experiment 3 consisted of 4 sessions completely identical to Experiment 1.

Conditional Response Probability Analysis The order in which items are recalled is not random; instead each retrieval event is influenced by items already recalled. To determine if valence drives recall order, we can measure participants' tendency to recall an item of a given valence conditionalized on the prior recall item's valence. For example, given that a positive valance word has just been recalled, what is the probability that the next recall will be a positive, neutral, or negative valence item? To measure this probability, we evaluated recall transitions as a function of valence. For each list, separate transition probabilities were calculated for each of 9 valence combinations (negative to negative, negative to positive, etc.). To account for the low likelihood of same valence transitions, we calculated the number of actual transitions as a function of possible transitions, based on the study items in the list and the items that had already been recalled. Therefore, the number of possible transitions could range from 0 to 15. The likelihood of a transition was calculated by dividing the number of actual transitions by the number of possible transitions. The number of actual transitions was always 0 or 1. In this way we accounted for the lower proportion of emotional items, and less likely transitions were given a greater value. If a neutral-neutral transition was made, and there were 7 available neutral items, the score for that transition would be 1/7. If a negative-negative transition was made and there were 2 available negative items, the score for that transition would be 1/2. Lists which had no positive or negative items, thus precluding any relevant transitions, were excluded from all analyses (on average 202 lists), resulting in on average 83 lists per participant. Probabilities were averaged across lists within participants and then across participants.

Results and Discussion

We measured probability of recall as a function of valence. On average, participants recalled 61% of negative words, 60% of neutral words, and 62% of positive words (Table 1). We ran a one-way repeated measures ANOVA comparing valence conditions and found a significant interaction (F(2, 302) = 11.5 $p <$ .01; $\eta_p^2 = .03$). Post-hoc comparisons using the Tukey HSD test indicated that the probability of recall differed significantly between both negative (M = .61, SD = .14) and neutral words (M = .60, SD = .14) as well as between positive (M = .62, SD = .14) and neutral words (M = .60, SD = .14). There was no difference in probability of recall for negative and positive words.

We observed reliably greater recall for both positive and negative items which is consistent with a large body of literature (Dolcos et al., 2004; Kensinger & Schacter, 2006). There is some evidence that memory is differentially enhanced for positive or negative items (Erk et al., 2003; Bennion et al., 2013). Such findings may be the result of task design as many highly emotional items could drive unintended mood changes in participants. By using a small proportion of emotional items, our study avoided this possible confound and showed a benefit for both positive and negative items. However, the small proportion of emotional items might make those items more distinctive and thus easier to remember than neutral items. To account for this possibility, we re-analyzed the data using equally distinctive emotional and neutral items (see Supplemental Information) and found that emotional items were still remembered better than neutral even when controlling for distinctiveness.

Memory enhancement for positive and negative items might be driven by contextual or salience mechanisms. If emotional features are integrated with context and used as a retrieval cue, then recall outputs should be clustered by valence, akin to various clustering phenomena whereby participants organize their recalls according to semantic, episodic and spatial associations (Bousfield, 1953; Kahana, 1996; Miller et al., 2013). To explore whether participants emotionally cluster their retrievals during recall, we calculated the likelihood of transitioning between words as a function of valence. Participants were more likely to transition between same valence items than different valence items and this tendency was greater than would be expected by chance as measured by repeatedly shuffling recall order and calculating transition probabilities on this permuted data (Figure 1). To test the significance of this valence clustering effect, we ran a 3 by 3 repeated measures ANOVA comparing valence of item transitioned from (positive, neutral, or negative) and valence of item transitioned to (positive, neutral, or negative). We found a main effect of item transitioned to (F(2, 302) = 18.8, $p < .01$ $\eta_p^2 = .09$) and an interaction effect (F(4, 302) = 28.2, $p < .01$; $\eta_p^2 = .18$). Post-hoc comparisons revealed that negative to negative transitions were significantly more likely than negative to neutral transitions (t(151) = 4.0, $p <$

.01; Cohen's d = .46) and positive to positive transitions were significantly more likely than positive to neutral transitions (t(151) = 2.8, $p < .01$; Cohen's d = .30; Bonferroni corrected for 2 tests, $p = .025$). This valence clustering effect was not driven by within list semantic similarity, as confirmed by a combined semantic-valence conditional response probability analysis (see Supplemental Information).

Together, these results suggest that contextual encoding and retrieval mechanisms may explain increased memory for emotional items. Previous research has suggested that contextual mechanisms may drive mood dependent and mood congruent memory effects (MDM, MCM; Bower, 1981; Lewis & Critchley, 2003), but MCM and MDM effects might represent a special case only relating to the mood-induction paradigm (Eich, 1995). Alternatively, the use of many emotional items could induce explicit strategy use that interferes with or overrides a natural context mechanism. Existing research has provided conflicting evidence as to whether emotion enhances (Doerksen & Shimamura, 2001) or impairs (Kensinger, 2009; Maddock & Frein, 2009) associative memory. Furthermore, a related study on the organizational effects of emotion on memory (Siddiqui & Unsworth, 2011) showed emotional clustering only when a valence orienting task (pleasantness judgment) was used. Together, these results suggest that a large percentage of emotional items might create subjective and variable strategies which may interfere with the associative mechanisms which support emotional clustering. In the current study, we found enhanced emotional memory and emotional clustering, both of which are consistent with predictions of retrieved context models (Howard & Kahana, 2002) and suggest that emotional information is incorporated into a slowly updating context representation during study and is used to cue retrieval of items at test. That this result occurs in the absence of mood induction suggests a general mechanism by which emotional items are better remembered than neutral items.

A leading theory of emotional memory enhancement suggests that emotional items receive increased attentional processing (Dolcos et al., 2004). It is possible that there are, in addition to the context effects observed here, independent attentional effects that increase the strength of the item. These attentional effects may be more directly related to arousal than valence (Kensinger, 2009). Alternatively, attention could interact with context by promoting item-to-context binding or increasing the salience of emotional features in context.

Conclusions

These results suggest that emotion is part of context, providing a potential mechanism for emotion regulation and mood persistence. A series of positive events might drive an individual to interpret later neutral experiences in a "positive light" and to retrieve other positive experiences, perpetuating their positive state. Likewise, a series of negative events could lead an individual to interpret neutral experiences in a “negative light,” perpetuating a negative state. Thus our results suggest that there may be a contextual mechanism driving emotion processing in our day to day experiences.

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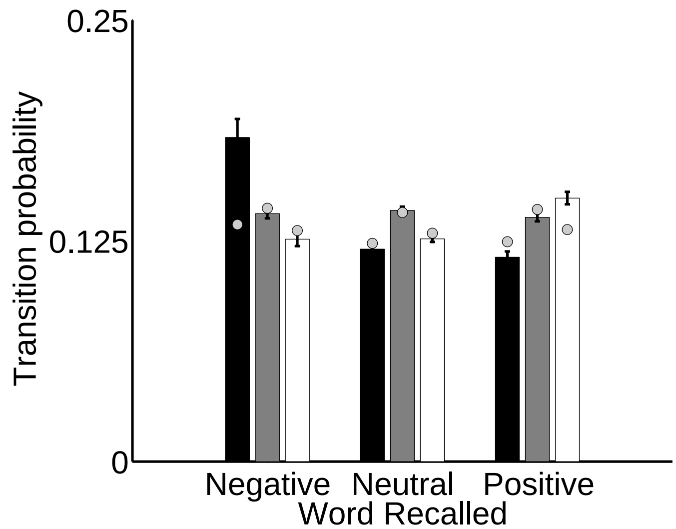
Negative	Neutral	Positive
.61 (.01)	.60 (.01)	.62 (.01)

Table 1. Recall probability as a function of valence. Average recall probability with standard error of the means in parentheses.

Figure Captions

Figure 1. Conditional response probability based on valence. For each list, the proportion of possible and actual transitions between the three valence categories was calculated. The y-axis shows the probability of making a transition to a particular valence item (black, negative; grey, neutral; white, positive) as a function of the just recalled item's valence (x-axis). Error bars are standard error of the mean. Transitions between similar valences (e.g. negative to negative, positive to positive) were significantly more likely than transitions between dissimilar valences (e.g. negative to neutral, positive to neutral).


0.25
0.125
0
Transition probability
Negative
Neutral
Positive
Word Recalled