

SUPPLEMENTARY MATERIALS

for

Positive emotion enhances association-memory

by Christopher R. Madan, Sarah M. E. Scott, & Elizabeth A. Kensinger

SUPPLEMENTARY EXPERIMENT 1

In the main experiment we found evidence that positive valence enhanced association-memory. This pattern counters the impairment in associative memory that is often revealed for negative-valenced items (e.g., Bisby & Burgess, 2014; Madan et al., 2012, 2017; Zimmerman & Kelley, 2010), consistent with the *valence hypothesis*. Here we used the words from Madan et al. (2012) and sought to replicate their finding of impaired associative memory for negative-valenced items. To rule out any differences based on the recruitment procedures used at Boston College and the University of Alberta (where Madan et al., 2012, was conducted), we recruited participants at both locations.

Methods

Participants

Boston College. Participants included 16 young adults (12 females), ranging from 18 to 22 years old ($M=19.48$, $SD=1.36$). Participants were screened and provided written consent as in the main experiment. No individual participated in more than one experiment.

University of Alberta. Participants included 30 young adults (demographic data not collected). Informed written consent was obtained from all participants prior to beginning the study, which was approved by the University of Alberta Institutional Review Board.

Materials

Word pairs were constructed using two pools of words: negative and neutral. These two word pools were identical to those used in Experiment 1 of Madan et al. (2012) for the Negative group. Words had been selected arousal, valence, and semantic relatedness ratings obtained in an initial norming study (see Madan et al., 2012, for further details), along with familiarity, imageability, word frequency, and word length measures obtained from MRC Psycholinguistic Database (Wilson, 1988).

Procedure

The procedure was identical to the main experiment, apart from the change of word pools. The paired-associate and final free recall tasks also proceeded identically as in Experiment 1 of Madan et al. (2012).

Results & Discussion

We conducted a PROBE [2: negative, neutral] x TARGET [2: negative, neutral] x SITE [2: Boston, Alberta] mixed ANOVA with the cued recall data. There was a significant effect of PROBE [$F(1,44)=7.16$, $p=.010$, $\eta_p^2=.14$], as well as a significant interaction [$F(1,44)=8.92$, $p=.005$, $\eta_p^2=.17$]. As shown in Figure S1, cued recall accuracy was best when both the probe and target were neutral words [$M=.52$], followed by equivalent performance in either case where the target word was negative [$M=.48$], and worst when the probe was a negative word and the target

was a neutral word [$M=.42$]. These findings replicate those of Madan et al. (2012) and indicate that arousing information can either enhance (Experiment 1: positive words) or impair (Experiment 2: negative words) associative memory, depending on emotional valence.

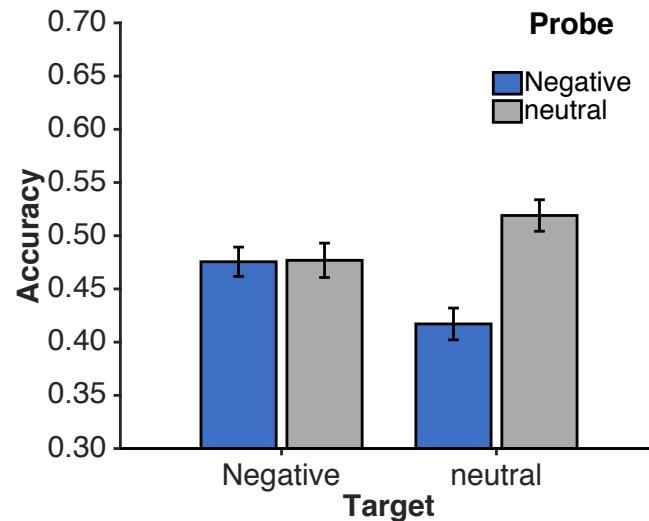


Figure S1. Cued recall accuracy from Supplementary Experiment 1, by probe and target type. Error bars are standard error of the mean, corrected for inter-individual differences.

SUPPLEMENTARY EXPERIMENT 2

In Supplementary Experiment 1 we demonstrated an impairment of association-memory for negative valence, contrasting with the enhancement of association-memory observed for positive valence in the main experiment. However, although the word pools of positive and negative words used in the main experiment and Supplementary Experiment 1 were both high in arousal, they were not matched for arousal. The positive words in the main experiment were less arousing than the negative words in Supplementary Experiment 1, raising the possibility that the enhanced associative memory in the main experiment was not caused by the positive valence but instead by the reduced arousal. See Appendix for characteristics of words used in all experiments. To test this possibility, we conducted an experiment using positive and negative words that Zimmerman and Kelley (2010) previously generated to be matched for arousal. Additionally, all three word pools (positive, negative, and neutral) were matched for word frequency, length, concreteness, imageability, and pairwise similarity (i.e., $LSA \cos(\theta)$). In Experiment 3, we tested memory for pairs of these stimuli, using pure-pair conditions (positive-positive, negative-negative, and neutral-neutral) and testing the effects of valence within-subject, as was done by Zimmerman and Kelley (2010). Supplementary materials report the results of an additional experiment in which mixed pairs were also used.

Methods

Participants

Boston College. Participants included 17 young adults (14 females), ranging from 18 to 21 years old ($M=18.71$, $SD=0.85$). Participants were screened and provided written consent as in the main experiment.

University of Alberta. Participants included 23 young adults (demographic data not collected). Participants were recruited and provided written consent as in Supplementary Experiment 1.

Materials

Word pairs were constructed using three pools of words: positive, negative, and neutral. Initially the word pools were generated by combining the pools from Experiments 3 and 4 of Zimmerman and Kelley (2010), which each had 28 words of each type (positive, negative, neutral). Words were removed that were relative long (e.g., ADVENTURE, HURRICANE) or short (e.g., ICE, BAT). This resulted in 48 positive and 48 negative words. We sought to have an equal number of emotional and neutral words, rather than equivalence across the valence levels. As such, we additionally supplemented the neutral word pool with words from Madan et al. (2012), to yield a total of 96 neutral words.

Procedure

The procedure was similar to the main experiment with the following changes. Each study set of eight pairs was comprised of two positive-positive pairs, two negative-negative pairs, and four neutral-neutral pairs. The paired-associate task proceeded for a total of 12 study sets.

Results & Discussion

Here we conducted a VALENCE [3: positive, negative, neutral] x SITE [2: Boston, Alberta] mixed ANOVA. As expected, Valence was a significant main effect [$F(2,74)=18.49$, $p<.001$, $\eta_p^2=.33$]. Neither the main effect of SITE nor the interaction was significant. Bonferonni-corrected post-hoc t -tests indicated that all three valence levels were significantly different from each other: Cued recall accuracy for positive pairs was the best [$M=.71$], followed by negative pairs [$M=.66$; positive vs. negative: $t(38)=2.71$, $p=.010$, $d=0.43$], with the lowest cued recall performance for the neutral pairs [$M=.60$; positive vs neutral: $t(38)=5.98$, $p<.001$, $d=0.96$; negative vs. neutral: $t(38)=3.22$, $p=.003$, $d=0.52$]. These results for positive pairs generally replicated those of Zimmerman and Kelley (2010, Exp. 3 and 4) although the results for negative pairs differed: Here, we found enhanced cued recall for negative compared to neutral pairs, while Zimmerman and Kelley (2010) reported no statistical difference between negative and neutral pairs. Importantly, our results—like those of Zimmerman and Kelley (2010)—confirm that, even when positive and negative words are equated for arousal, positive word pairs are associated with better cued recall than negative word pairs. These results favor the *valence hypothesis* over the *arousal hypothesis*.

SUPPLEMENTARY EXPERIMENT 3

In Supplementary Experiment 2, we again found evidence of an enhancement of association-memory due to positive emotion, and the results confirmed that even when positive and negative stimuli are equated for arousal, positive stimuli lead to better associative memory than negative stimuli. However, because we had used a stimulus set from Zimmerman & Kelley (2010) in Supplementary Experiment 2, only pure-pairs (both words of the same valence) and not mixed pairs (one neutral and one valenced word) were used. In this supplementary experiment, we selected new word lists that were tightly matched on arousal and absolute valence and examined the effects of both positive and negative valence on association-memory within-subjects, using all pair types (mixed-pairs as well as pure-pairs).

Methods

Participants

Participants included 63 young adults (52 females), ranging from 18 to 22 years old ($M=19.33$, $SD=1.08$), recruited at Boston College. Participants were screened and provided written consent as in the main experiment. One participant withdrew during the experiment session because they were falling asleep.

Materials

Word pairs were constructed using three pools of words: positive, negative, and neutral. As in the main experiment, word properties were obtained from Warriner et al. (2013) and the MRC Psycholinguistic Database (Wilson, 1988). Words were selected such that the positive and negative word pools were matched for arousal and absolute valence; all three word pools were matched on all remaining word properties, apart from valence and dominance. The positive and negative word pools consisted of 40 words each, while the neutral word pool consisted of 80 words. See Table S1 for the word pool statistics. As intended, emotional and neutral word pools differed for arousal [$t(158)=12.30$, $p<.001$] and absolute valence [$t(158)=29.29$, $p<.001$].

We also calculated LSA $\cos(\theta)$ as a measure of within-pool word similarity (Landauer & Dumais, 1997). LSA $\cos(\theta)$ for each word pool is as follows ($M\pm SD$): positive (0.20 ± 0.14), negative (0.16 ± 0.13), and neutral (0.07 ± 0.09). Independent-sample t-tests (with df adjusted based on the effective number of independent comparisons) of the LSA $\cos(\theta)$ values suggest that the pools were similar in their semantic cohesiveness [all p 's $>.1$].

	Positive	Negative	neutral	Between-pool statistics
Valence	7.14 (0.42)	2.83 (0.56)	5.30 (0.36)	P > n > N
Arousal	4.61 (1.09)	4.63 (0.67)	3.27 (0.37)	P = N > n
Abs. Valence	2.14 (0.42)	2.17 (0.56)	0.40 (0.25)	P = N > n
Dominance	6.26 (0.85)	3.88 (0.74)	5.46 (0.52)	P > N > n
Familiarity	501.00 (45.81)	505.77 (49.35)	496.96 (43.81)	
Imageability	438.32 (62.87)	465.07 (76.42)	440.65 (93.99)	
Word Frequency	30.25 (21.15)	22.50 (17.70)	28.59 (27.22)	
N. of Letters	6.88 (0.65)	6.70 (0.72)	6.74 (0.72)	
N. of Syllables	2.35 (0.48)	2.25 (0.44)	2.21 (0.41)	
LSA cos(θ)	0.20 (0.14)	0.16 (0.13)	0.07 (0.09)	

Table S1. Word property statistics for Supplementary Experiment 3 based on normative ratings from Warriner et al. (2013), Wilson (1988), and Landauer and Dumais (1997). Mean ratings are shown with standard deviation in parentheses. P, positive; N, negative; n, neutral. Between-pool statistical differences are listed in the last column, based on $p < .05$; pools do not differ unless otherwise stated. See text for further details about each measure.

Procedure

The procedure was nearly identical to that of the main experiment, with the following changes. Each study set used one of the emotional word pools (positive or negative) along with the neutral word pool. Across every two study sets, participants were given one study set involving positive words and one study set involving negative words. In the positive sets, each study set was still comprised of eight pairs and was comprised of positive-positive, positive-neutral, neutral-positive, and neutral-neutral pairs, with two pairs of each type presented. Similarly, in the negative sets, participants were given eight pairs comprised of negative-negative, negative-neutral, neutral-negative, and neutral-neutral pairs, with two pairs of each type presented. The total number of study sets was increased to ten (from eight).

Data Analysis

One participant was excluded for having mean accuracy below 10%.

Results & Discussion

Here we conducted a PROBE [2: emotional, neutral] x TARGET [2: emotional, neutral] x VALENCE [2: positive, negative] repeated-measures ANOVA. None of the effects were significant. These null effects may relate to the relatively lower number of trials per condition in

this experiment as compared to the prior experiments (which either tested only one valence [main experiment and Supplementary Experiment 1] or only used pure-pairs [Supplementary Experiment 2]). As shown in Figure S2, cued recall accuracy was numerically (but not statistically) higher when the cued recall probe was positive rather than neutral. Surprisingly, for the negative blocks, we also observed numerically better cued recall for the negative-negative pairs than for the other conditions.

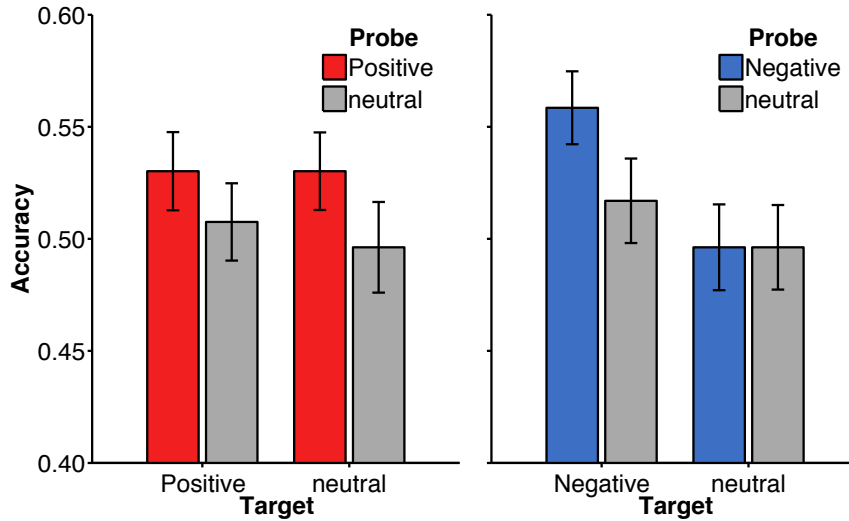


Figure S2. Cued recall accuracy from Supplementary Experiment 3, by probe and target type, for each block of pairs. Error bars are standard error of the mean, corrected for inter-individual differences.

SYSTEMATIC COMPARISON OF WORD PROPERTIES

As several different word pools were used in the experiments presented here, we decided to conduct a systematic comparison on the words used in each experiment. For these comparisons we used the valence and arousal ratings from Warriner et al. (2013). Importantly, neither Madan et al. (2012) nor Zimmerman and Kelley (2010) used this database in their studies, likely leading to the word pools appearing less constrained/distinct in these analyses. However, the use of ratings from a single source was necessary to be able to appropriately compare the word properties. Figure B1 shows the valence, arousal, and absolute valence for all of the words from the present study, as well as from Experiments 3 and 4 of Zimmerman and Kelley (2010).

Words in the main experiment and Supplementary Experiment 3 were selected directly from the Warriner et al. database. As a reminder, the words used in Supplementary Experiment 1 are identical to those from the negative group of Madan et al. (2012); words in Supplementary Experiment 2 were selected from Zimmerman and Kelley (2010). To compare word properties between pools, we used a Wilcoxon-Mann-Whitney rank-sum test on the word rating scores.

We first compared the positive and negative words between the main experiment and Supplementary Experiment 1. As shown in Figure S3, these two emotional word pools differed in both arousal [$Z=5.67, p<.001$] and absolute valence [$Z=2.69, p=.007$], with negative words being higher on each dimension. In Experiment 3, arousal ratings were matched between positive and negative word pools [$Z=1.42, p=.16$], though there were differences in absolute valence [$Z=2.94, p=.003$], with negative words being higher. In Supplementary Experiment 3, positive and negative words were matched for both arousal [$Z=0.24, p=.98$] and absolute valence [$Z=0.24, p=.98$].

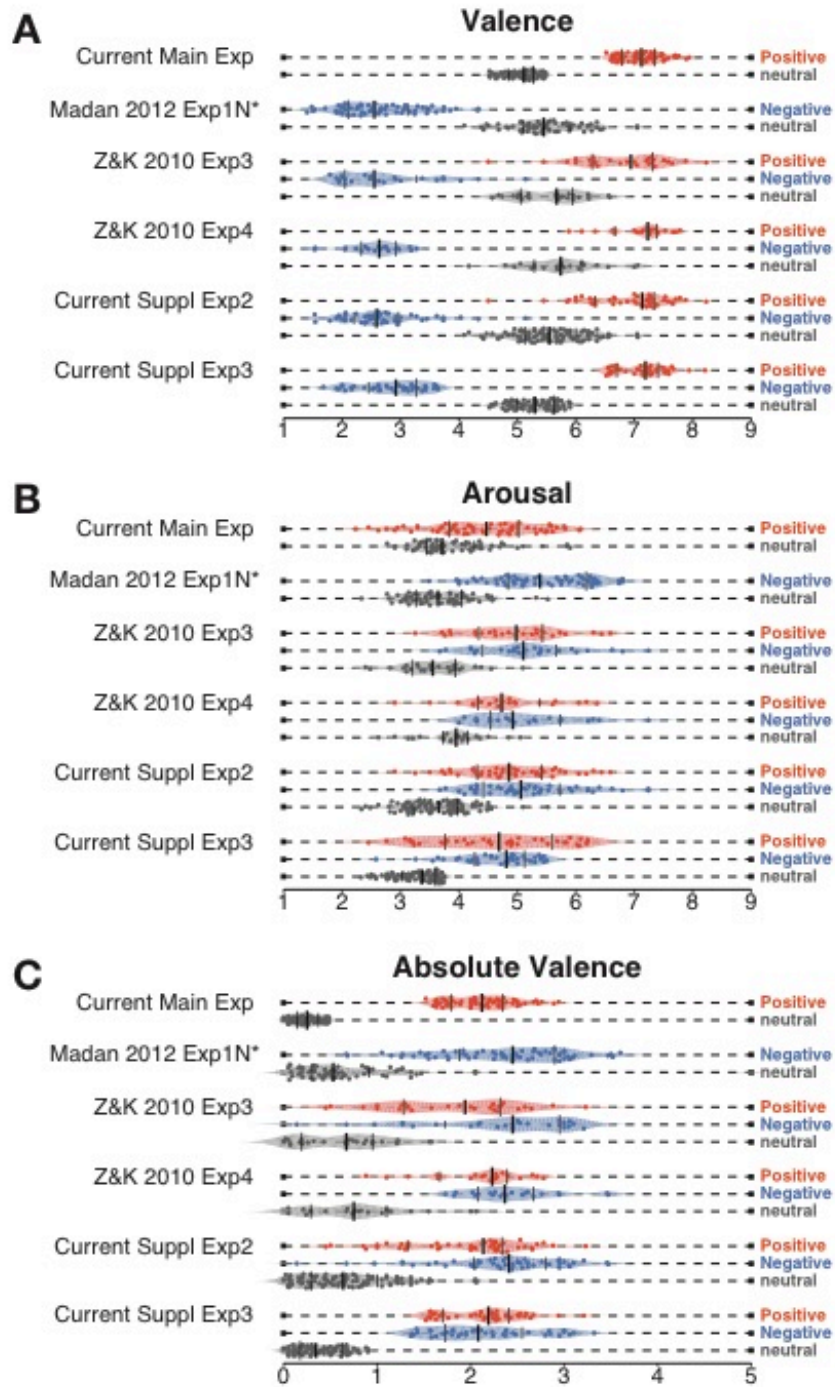


Figure S3. Violin plots of the distributions for the word property ratings for each word pool used in the current experiments, as well as those from Zimmerman and Kelley (2010) (denoted as ‘Z&K 2010’). Each dot represents a word; tick marks denote the median, as well as 25th and 75th percentiles. (A) Valence and (B) arousal ratings were obtained from the Warriner et al. (2013) database. (C) Absolute valence is also presented, calculated as $|5 - \text{valence}|$. * denotes that the word pools used in Supplementary Experiment 1 of the current paper are identical to those used in the Negative group of Madan et al. (2012, Experiment 1).

REFERENCES

- Bisby, J. A., & Burgess, N. (2014). Negative affect impairs associative memory but not item memory. *Learning and Memory, 21*, 760-766.
- Landauer, T. K., & Dumais, S. T. (1997). A solution to Plato's problem: The latent semantic analysis theory of acquisition, induction, and representation of knowledge. *Psychological Review, 104*, 211-240.
- Madan, C. R., Fujiwara, E., Caplan, J. B., & Sommer, T. (2017). Emotional arousal impairs association-memory: Roles of amygdala and hippocampus. *NeuroImage, 156*, 14-28.
- Madan, C.R., Caplan, J.B., Lau, C.S.M., Fujiwara, E., (2012). Emotional arousal does not enhance association-memory. *Journal of Memory and Language, 66*, 695-716.
- Warriner, A. B., Kuperman, V., & Brysbaert, M. (2013). Norms of valence, arousal, and dominance for 13,915 english lemmas. *Behavior Research Methods, 45*, 1191-1207.
- Wilson, M. D. (1988). The MRC psycholinguistic database: Machine readable dictionary, version 2. *Behavior Research Methods, Instruments, & Computers, 20*, 6-11.
- Zimmerman, C.A., & Kelley, C.M. (2010). "I'll remember this!" Effects of emotionality on memory predictions versus memory performance. *Journal of Memory and Language, 62*, 240-253.