Trauma Level and Intrusions in Emotional Memory

Evidence from Externalized Free Recall

by

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ABSTRACT

The emotional enhancement of memory (EEM) has consistently suggested that memory performance is enhanced for positively and negatively valenced stimuli. Heightened arousal and activation of the noradrenergic system facilitates encoding and the formation of memory traces. However, this EEM can become maladaptive when coupled with the heightened noradrenergic activity associated with posttraumatic stress disorder (PTSD). This heightened noradrenergic response can result in chronic intrusive memories of past traumatic events. This study aims to explore overall recall, retrieval dynamics, output editing, and intrusions as a function of emotional content and prior history with traumatic experiences. Undergraduate students (N=249) from Arizona State University completed a battery surveys measuring PTSD symptomatology and other related constructs including anxiety, depression, and trauma. Participants then completed a memory task, an externalized free recall task for multiple study-blocks utilizing word list stimuli. During recall, participants were instructed to report every word that came to mind regardless of whether it was present or not in the most recent study-block, then make a judgment about recent-list membership. Main effects of valence were found for recall accuracy, intrusion generation, and successful editing. This suggests that the emotional enhancement of memory does in fact play a role in intrusion generation and the ability to edit out false recollections. Only depression levels resulted in a significant interaction effect with valence, specifically when measuring intrusion generation. This suggests that trauma level does not play a significant role in emotional intrusion memory.

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CHAPTER 1

INTRODUCTION

Emotional Memory and Traumatic Experiences

Numerous research has replicated the phenomenon that emotional stimuli are more easily and vividly remembered than neutral stimuli. There seems to be an evolutionary link to this in that it helps us to better remember dangers, and in turn better avoid them in the future. However, what happens when you have an overactive emotional memory? Posttraumatic stress disorder (PTSD) is the chronic re-experiencing of a life-threatening event (APA, 2013), and includes the overactive remembering of highly emotional events. The connections between emotional memory and PTSD are further solidified by the fact that the noradrenergic system plays a critical role in the performance of both.

The emotional enhancement of memory (EEM) refers to better memory performance for negative and positive stimuli, in that respective order, compared to neutral stimuli. However, alongside this increase in true memory for emotional stimuli, there is also an increase in false memories (Bessette-Symons, 2018). It is thought that because emotional memories tend to be gist traces rather than verbatim traces, the memories are more susceptible to distortions and misremembering during recalls.

The primary brain region that facilitates emotional memory is the amygdala. The amygdala is what gives an ‘emotional stamp’ to stimuli and is critical to the formation of lasting emotional memories (Dolcos, LaBar, & Cabeza, 2004; Richardson, Strange, & Dolan, 2004; Ritchey, Dolcos, & Cabeza, 2008). The *memory modulation* theory proposes that amygdala activation during the encoding of emotionally arousing material modulates the medial temporal lobe (MTL) system, specifically the hippocampus, a brain region that plays a major role in learning and memory (McGaugh, 2004). The increase of arousal from emotional stimuli increases the coactivation of the amygdala and hippocampus, and in turn increases persistence of the memory trace formed (Bessette-Symons, 2018). The underlying mechanism behind this coactivation is the noradrenergic system.

The amygdala and hippocampus are connected via the noradrenergic system. The noradrenergic response that facilitates the consolidation of emotional memory traces. In short, emotional arousal triggers two primary stress systems: the hypothalamic-pituitary-adrenal (HPA (axis) and the autonomic nervous system (ANS). The HPA system is slow-acting and results in the release of cortisol from the adrenal cortex. Parallel to this, activation of the ANS, often referred to as the "flight, fight, or freeze response, results in a fast-acting noradrenergic response. The basolateral amygdala (BLA) specifically influences noradrenergic activation, and response from the BLA interacts with circulating cortisol, resulting in amygdala and hippocampal mediated consolidation. This memory consolidation process is especially strong in response to high arousal stimuli, which trigger a stronger amygdala response, noradrenergic release, and subsequent memory connectivity and consolidation (Kensinger & Corkin, 2004). However, this biological EEM process can become maladaptive when negative salient memories are strengthened and become intrusive and chronic.

Patients with PTSD tend to have a hyperactive amygdala and noradrenergic system which facilitates maladaptive emotional memory. Stress exposure leads to morphological effects on neurons and synapses in both the amydala and hippocampus

(Roozendaal, McEwen, & Chattarji, 2009). Cellular structural changes may underly the hyperactive amygdala and hyperactive adrenergic response along with it, and results in higher norepinephrine levels within cerebrospinal fluid (Geracioti Jr., Baker, Ekhator, West, Hill, Bruce, Schmidt, Rounds-Kugler, Yehuda, Keck, & Kasckow, 2001). Norepinephrine (NE)is a critical neurotransmitter in stress response and the noradrenergic system. Thus, those with PTSD are in a chronic, sustained hyperactive stress response state within their central nervous system. In fact, animal models have found that injecting rats with norepinephrine can induce PTSD-like fear responses (Liu, Zhu, Hao, Shi, Wang, Xue, & Zhao, 2019; Rajbhandari, Baldo, & Bakshi, 2015). Heightened amygdala levels and functional connectivity between the amygdala and hippocampus have been found in PTSD emotional memory studies (Brohawn, Offringa, Pfaff, Hughes, & Shin, 2012; Durand, Isaac, & Januel, 2019). The hyperactive amygdala, alongside heightened levels of NE, makes for more active emotional memory formation, and more vivid retrieval.

Computational Models of Memory

Computational models of memory attempt to construct how mood and emotional valence modulate episodic memory. Cohen & Kahana (2022) developed the CMR3 model based on the retrieve-context theory, in order to account for how memory and mood interact in emotional disorders. The retrieved-context theory focuses on the episodic context in which a memory is encoded. This context is then encoded into a network of associations and facilitates later activation and retrieval. These networks allow semantic associations, as well as the episodic, to form and guide memory retrieval. A cyclical pattern of encoding is then formed every time a memory is retrieved. A new episodic context is encoded when a memory is reactivated, and the breadth in which perceptual cues can trigger reactivation expands. Thus, this recursive process both updates a memory with new information, and also makes it more susceptible to unwanted retrieval.

Intrusive memories are a prominent symptom of PTSD. In the retrieved-context theory, it is stimuli that share strong associations and perceptual similarity to stimuli that preceded the traumatic event that serve as cues for unwanted retrieval. Thus, it is these “trauma cues” (Cohen & Kahana, 2022), that trigger intrusion memories, and do not need to share any semantic similarity to the actual traumatic event itself. Thus, Cohen & Kahana (2022) proposed that any high-arousal, negative event can potentially facilitate intrusive memories. These disturbances in memory and attention are not limited to only trauma-related content as well (Jelinek, Jacobsen, Kellner, Larbig, Biesold, Barre, & Moritz, 2006).

PTSD may result in memory intrusions due to a shallower level encoding during traumatic events. This is because PTSD has been found to be more connected to data-driven processing (DDP) than conceptual processing (Halligan, Clark, & Ehlers, 2002). DDP is the processing of sensory and perceptual information rather than the meaning of an event. This perceptual encoding is more susceptible to involuntary recall, as new stimuli are more readily matched to the encoding context of the traumatic event. Meanwhile, conceptual processing focuses on the meaning of an event, and results in more elaborative encoding. This elaboration inhibits unintentional retrieval. DDP during trauma-exposure increases the probability of developing PTSD symptoms due to increasing the degree of memory disorganization (Halligan, Clark, & Ehlers, 2002).

Repetition plays a large role in memory and can aid memory intrusions in PTSD. The retrieved-context theory predicts that spaced repetitions of stressors increase the number of contexts in which a traumatic event is associated with. This in turn allows for the creation of more perceptual cues for spontaneous retrieval of the event's memory trace. Cohen & Kahana's (2022) model was found to support the Autobiographical Memory Theory (AMT) of intrusive memories in PTSD, and that it is this repeated rehearsal that causes a memory trace to be associated with multiple contexts. Thus, this repeated rehearsal increases the probability of future perceptual contexts to contain a cue associated with the memory trace, and trigger activation and retrieval, even if the original episodic context has little connection to the new one.

Externalized Free Recall

Externalized free recall (EFR) is a paradigm that allows the dynamics of correct and incorrect recalls to be examined. In the traditional free recall model, memory intrusions, or incorrect recalls, are not usually produced. This is because participants are able to edit them out and prevent memory intrusions from being recalled. Thus, EFR allows these intrusions to be vocalized by utilizing the editing phase as a part of the procedure.

EFR is based on generate-edit models, with recall being split into two phases: item generation and item editing. At the presentation of a stimuli, items are generated based on an overlap between the general context cue and items stored in memory. The items generated then undergo an editing, or monitoring, process to determine whether a generated item is correct. This then allows the items retrieved to either be selected for recall or be discarded. Generate-edit models suggest that both correct and incorrect recalls are made, but only the correct are recalled due to highly efficient editing.

Similar to the retrieved-context theory, generate-edit models are based on a cyclical and cumulative process of retrieval. Memory begins with a general context cue, which then probes the generation of items. However, consecutive retrievals then build off of each other and are based off of the general context cue and the last retrieved item. This cyclical process continues until a certain number of failures is reached.

The EFR paradigm minimizes this editing process and allows for intrusion generation to become more apparent. This is done by instructing participants to recall words presented in a list and any words that come to mind during the testing period. Participants are also instructed to indicate if they believe a word is incorrect, or not presented on the list. This allows intrusions to be generated, recalled, and judged. The judgment of their responses creates two different types of intrusions. The first is previous list intrusions (PLIs), these are words that were not presented on the most recent list but were presented on a previous one. The second is extralist intrusions (ELIs): these are words that were not presented on any list. It is important to note that ELIs still tend to be phonologically or semantically related to a current target.

Unsworth, Brewer, & Spillers (2010) found that the majority of intrusions are correctly identified as incorrect, but the editing process itself is dependent on a number of factors. Serial position was a large factor. They found that participants were more likely to reject a response, or identify it as incorrect, later on in the recall period. It was also less likely for a response to be rejected after the recall of a correct item. PLIs were also less likely to be rejected if they came from a further back list. This is known as the PLIrecency effect (Zaromb, Howard, Dolan, Sirotin, Tully, Wingfield, & Kahana, 2006). This suggests that strong contextual overlap leads to greater confusion. This aligns with the retrieved-context theory, in which items with network associations facilitate retrieval. Participants were also fairly successful at rejecting an intrusion in the last output position and may have aided the decision to terminate recall. Unsworth, Brewer, & Spillers (2010) also replicated a clustering effect, in which response types were more likely to be made in groups. For example, PLIs were more likely to be generated and rejected after another PLI.

Current Study

The current study utilized an EFR paradigm coupled with neutral, positive, and negative emotional word stimuli in order to explore how both emotional valence of stimuli and trauma level modulates memory intrusions. Based on prior literature, we tested two hypotheses; 1) emotional valence stimuli will have higher recall accuracy, more intrusions, and less successful editing compared to neutral stimuli; 2) higher levels of trauma history and/ or psychiatric symptoms will predict higher recall accuracy, more intrusions, and lower editing success, specifically for negative.

CHAPTER 2

METHODOLOGY

Participants and Design

The participants were 249 undergraduate students pooled from the PSYC 101 classes at Arizona State University using the SONA system. The participants were between the ages of 18 and 42 and received course credit for their participation. The participants performed six lists of 10 words each. The words were 1,024 nouns (243 positive, 447 neutral, 344 negative) selected from Bradley & Lang (1999) and were randomly selected for each list. Thus, all participants viewed unique lists that were randomly created at data collection.

Groups

Participants were assigned to either a low or high trauma level group. Four questionnaires were given to measure trauma level. These included the Brief Trauma Questionnaire (BTQ; Schnurr, Vielhauer, Weathers, & Findler, 1999), the Post Traumatic Stress Disorder Checklist (PCL-5; Weathers, Litz, Keane, Palmieri, Marx, & Schnurr, 2013), the Patient Health Questionnaire (PHQ2; Kroenke, Spitzer, & Williams, 2001), and the Generalized Anxiety Disorder 2-item (GAD-2; Spitzer, Kroenke, Williams, & Löwe, 2006). Measures of depression and anxiety were included due to the comorbidity and overlap of symptoms (include citations). The scores of each questionnaire were summed to calculate the clinical predictors.

Procedure

After completing informed consent, a pre-screening questionnaire to obtain demographics and PTSD symptom levels will be given. This questionnaire will obtain age, education level, ethnic, income, and employment information. The four trauma surveys were given at this time as well. Participants then completed the externalized free recall task.

Participants were tested individually. Words were presented visually for 1 sec each with a 1 sec blank screen in between the presentation of each word. A total of 12 words were presented per list, with 4 words of each valence. After each list presentation, the participants completed a 16 sec distractor task before recall: the participants were presented eight 3-digit numbers for 2 sec each and were required to type the digits in descending order after each item. At recall, participants were presented three question marks in the middle of the screen. The participants were instructed to not only recall all of the items from the most recent list, but to also recall any other words that come to mind during the recall phase, even if they know that the word was not included in the most recent list. Furthermore, participants were instructed that if they recall a word, they knew was incorrect, to press the spacebar to indicate that the response is incorrect. Participants were given 45 sec to recall as many words as possible in any order they wished. The participants typed their responses and were instructed to press the "Enter" key after each response, clearing the screen. If participants typed a word that they knew was incorrect (intrusions and repetitions), they were instructed to press the spacebar before pressing the "Enter" key (Figure 1). Prior to the practice and test trials, participants received a brief typing exercise (typing the words *one-ten*) to assess their typing efficiency.

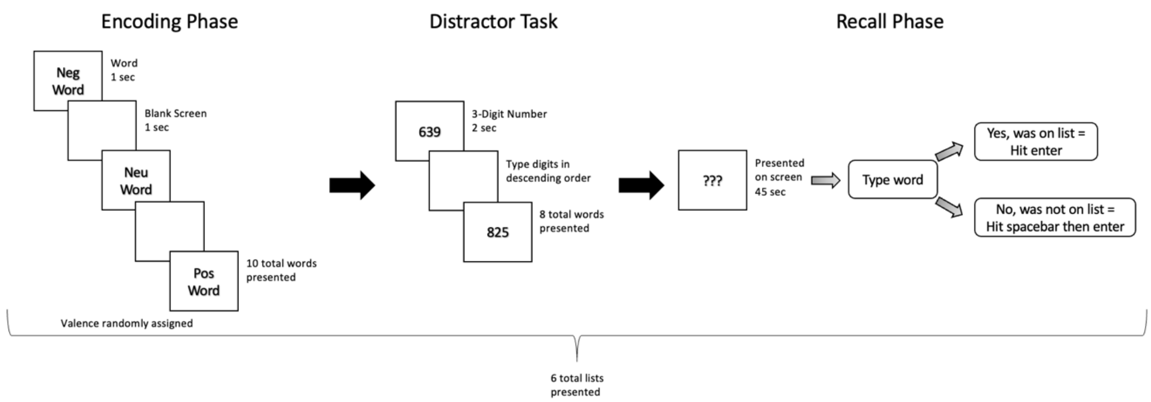


Figure 1. Externalized free recall paradigm of emotional word stimuli.

CHAPTER 3

RESULTS

The results are organized into two sections. In the first section, the effects of emotion on the externalized free recall of words were examined. In the second section, the interactions between the clinical predictors and emotional valence were examined.

Emotional Valence and Recall Performance

Variables to compute recall accuracy, intrusion generation, and edited intrusions by valence were created. A variable for each valence was created for all three. The variables for accuracy were created by matching successful recall to the respective valence of the word recalled. They were named; pos_acc_sum, neutral_acc_sum, and negative_acc_sum. The variables for intrusions were created by matching recall of words not on the most recent list and their respective valence. They were named; pos_int_sum, neutral_int_sum, and negative_int_sum. Lastly, the editing variables were created by matching recall of words not on the most recent list, if the participant indicated it wasn't on the list, and the word's respective valence. They were named; pos_int_edit_sum, neutral_int_edit_sum, and negative_int_edit_sum.

Table 1

Descriptive Statistics

Variable	**N**	**Minimum**	**Maximum**	**Mean**	**SD**
pos_acc_sum	201	0	20	10	3.99
neutral_acc_sum	201	0	14	4.73	2.67
negative_acc_sum	201	0	19	7.06	3.30
pos_int_sum	201	0	17	4.62	2.81
neutral_int_sum	201	0	17	3.31	2.64
negative_int_sum	201	0	11	2.81	2.26
pos_int_edit_sum	201	0	17	2.92	1.97
neutral_int_edit_sum	201	0	9	1.88	1.55
negative_int_edit_sum	201	0	9	1.70	1.41
BTQ	224	0	6	1.67	1.52
PCL-5	223	0	70	19.67	17.60
PHQ2	224	0	6	1.50	1.59
GAD-2	224	0	6	2.07	1.88

On average, participants accurately recalled 10 (SD = 3.99) positive words per list, 4.73 (SD = 2.67) neutral words per list, and 7.06 (SD = 3.30) negative words per list (Table 1). A repeated measures general linear model was conducted to analyze the relationship between emotional valence and recall accuracy. The model predicting recall accuracy from emotional valence accounted for a significant amount of variance, F (2, 199) = 185.17, $p < 0.001$ (Table 2). Positively valenced words had the highest recall accuracy, followed by negative words, then neutral words (Figure 2). This replicates the emotional enhancement of memory, with neutral words having the lowest recall accuracy. However, it does not replicate the enhancement of negative stimuli over positive stimuli.

Table 2

Emotional Valence and Recall Performance

Variable	Sum of Squares	df	Mean Square	F	Sig.
Valence x Accuracy	2806.97	2	1403.44	185.17	<0.001
Valence x Intrusions	351.35	2	175.68	39.272	<0.001
Valence x Edits	173.20	2	86.60	38.03	<0.001

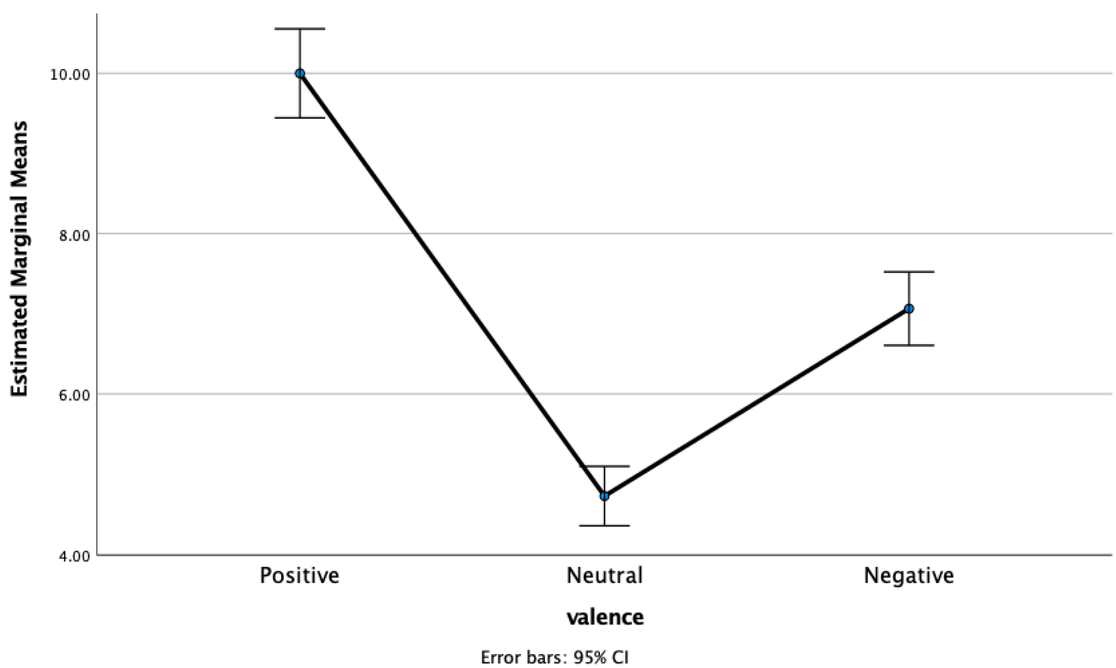


Figure 2. Recall accuracy as a function of valence.

On average, participants generated 4.62 (*SD* = 2.81) positively valenced intrusions per list, 3.31 (*SD* = 2.64) neutrally valenced intrusions per list, and 2.81 (*SD* = 2.26) negatively valenced intrusions per list (Table 1). A repeated measures general linear model was conducted to analyze the relationship between emotional valence and intrusion generation. The model predicting intrusion generation from emotional valence accounted for a significant amount of variance, F (2, 199) = 39.272, $p < 0.001$ (Table 2). Positively valenced words had the highest intrusion generation rate, followed by neutral words, then negative words (Figure 3). This does not support the retrieved-context theory, in that negatively valenced words did not produce more intrusions due to heightened emotional arousal (Cohen & Kahana, 2022).

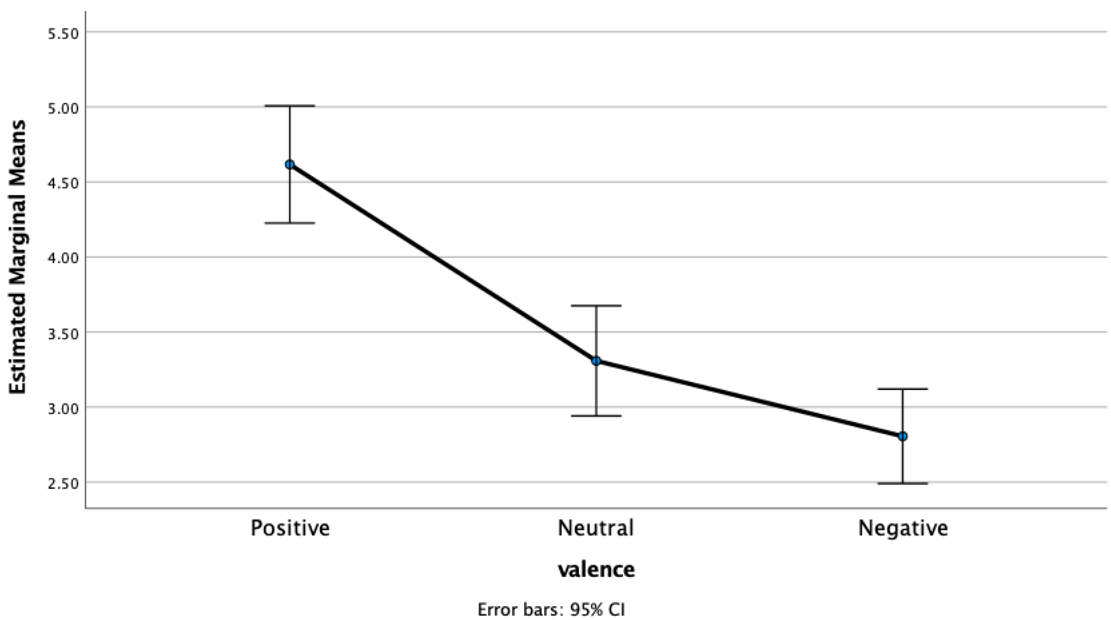


Figure 3. Intrusion generation as a function of valence.

On average, participants successfully edited 2.92 (*SD* = 1.97) positive words per list, 1.88 (*SD* =1.55) neutral words per list, and 1.70 (*SD* = 1.41) negative words per list (Table 1). A repeated measures general linear model was conducted to analyze the relationship between emotional valence and intrusion editing success. The model predicting editing success from emotional valence accounted for a significant amount of variance, F (2, 199) = 38.034, $p < 0.001$ (Table 2). Positively valenced words had the highest editing success, followed by negative words, then neutral words (Figure 4). This somewhat replicates the emotional enhancement of memory, with neutral words having the lower editing success than positive words. However, this does support the theory that heightened emotional arousal also facilitates false recollection and recall of memory traces, especially negatively valenced ones (Bessette-Symons, 2018). This also supports the retrieved-context theory, as the cyclical nature of re-encoding due to semantic network associations being triggered may increase a false sense of familiarity (Cohen & Kahana, 2022).

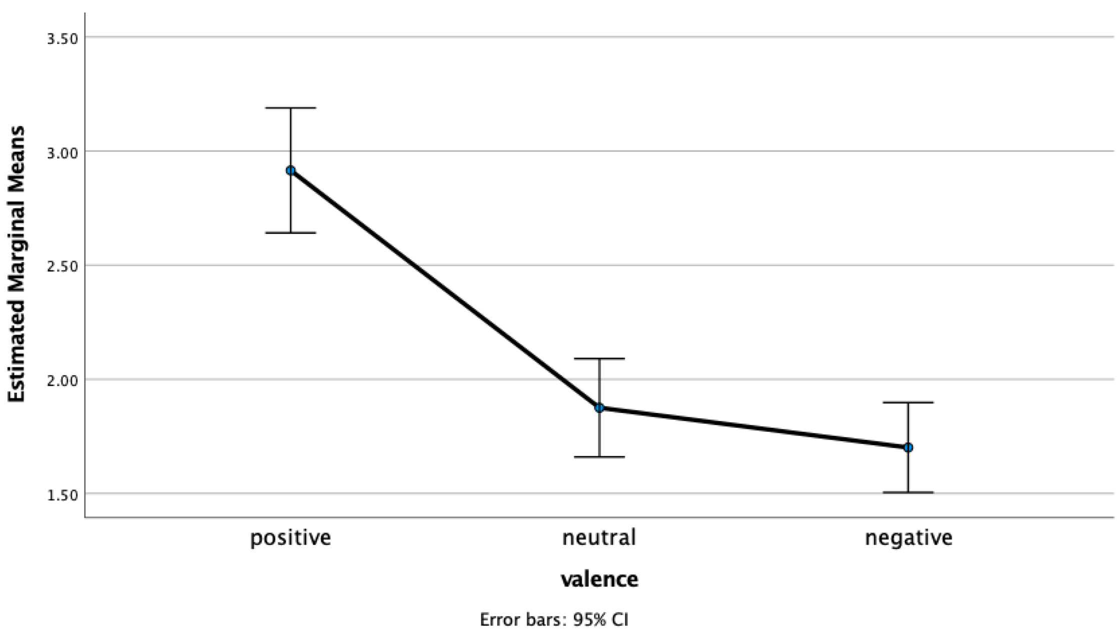


Figure 4. Editing success as a function of valence.

Emotional Valence and Clinical Measures of Trauma

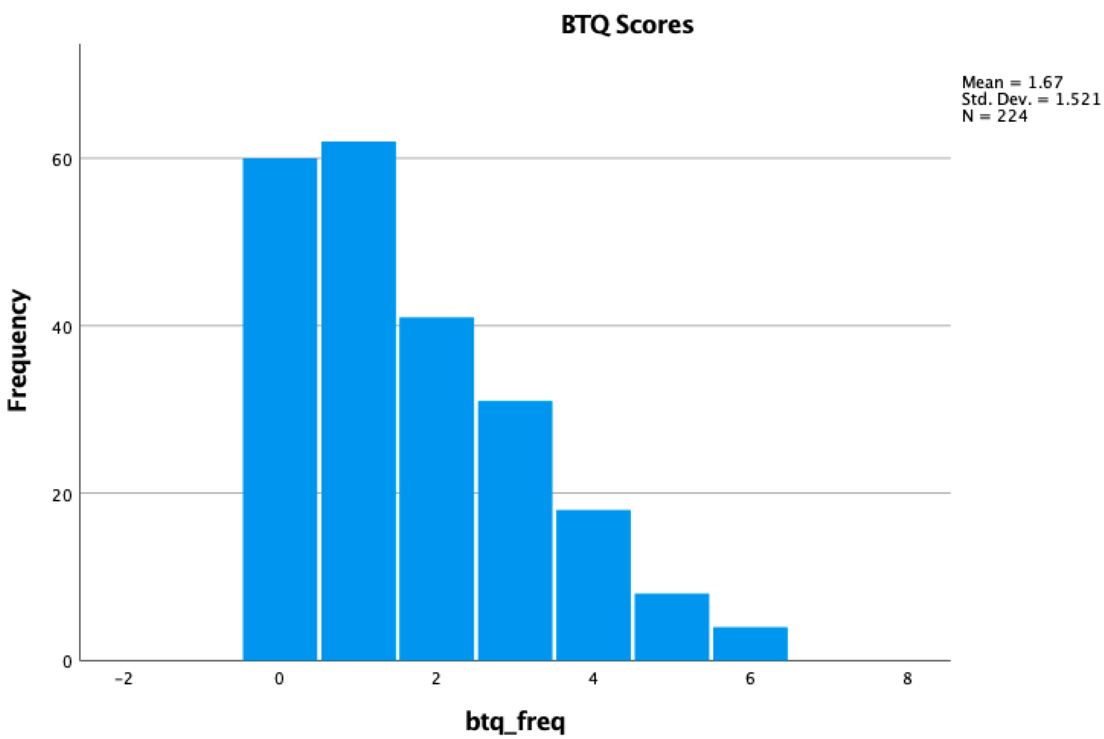
Table 3

Descriptive Statistics and Correlations for Survey Scores

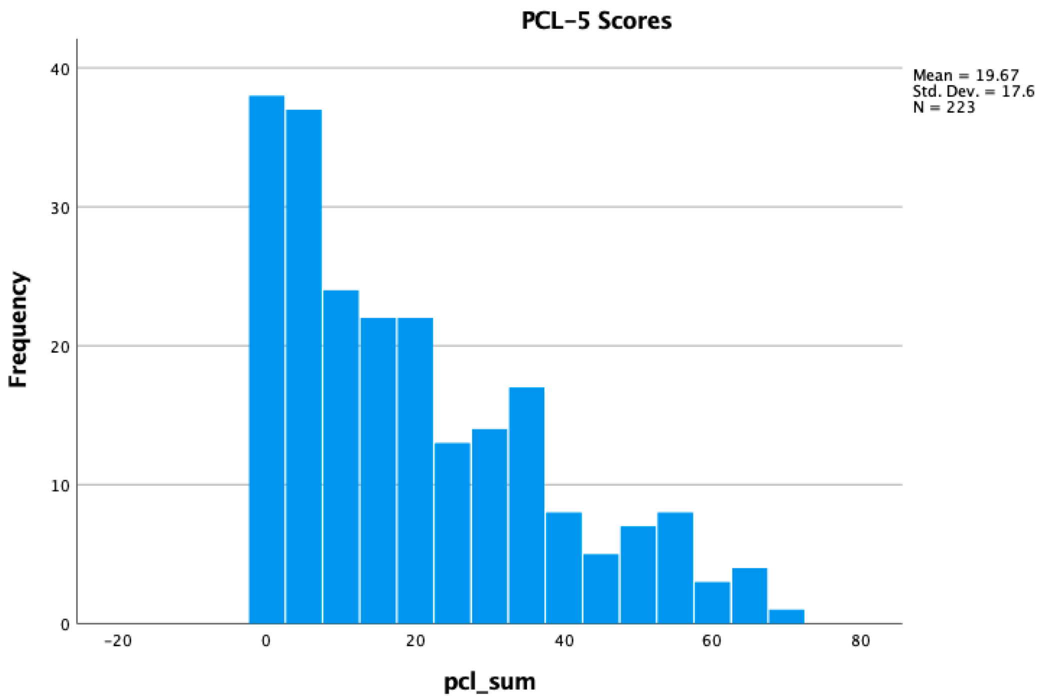
Variable	*n*	*M*	*SD*	BTQ	PCL-5	PHQ2	GAD-2
BTQ	224	1.67	1.52	-	-	-	-
PCL-5	223	19.67	17.69	0.44**	-	-	-
PHQ2	224	1.50	1.59	0.28**	0.60**	-	-
GAD-2	224	2.07	1.88	0.37**	0.61**	0.63**	-

First, a correlation matrix of the surveys was conducted (Table 3). All four surveys were significantly correlated with each other. However, it is important to note that all the means were below half of the maximum score for each survey. This may suggest a small variability in the clinical measures (Figure 5).

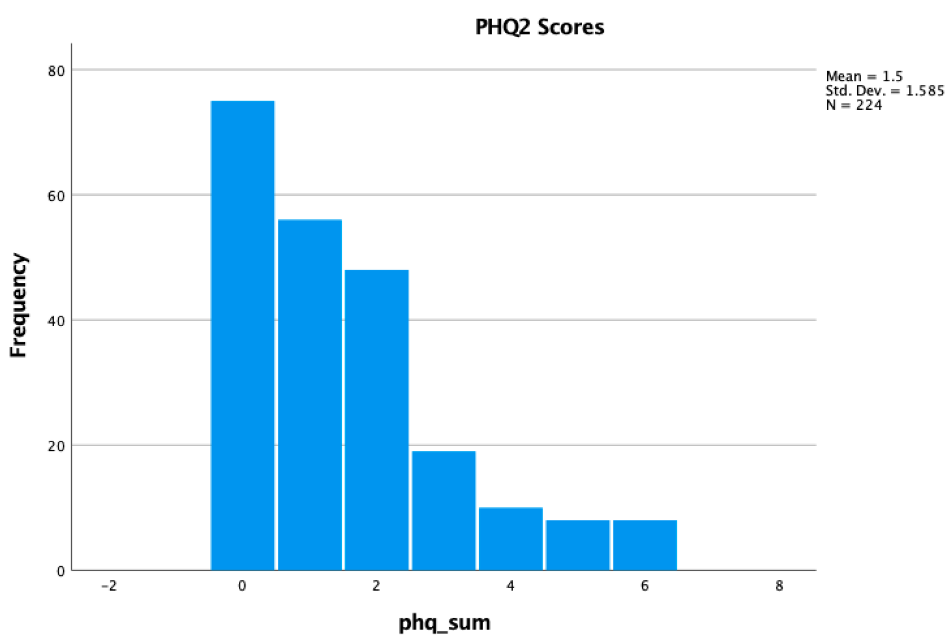
A.



B.


PCL-5 Scores
Mean = 19.67
Std. Dev. = 17.6
N = 223
Frequency
40
30
20
10
0
-20
0
20
40
60
80
pcl_sum

C.


PHQ2 Scores
Mean = 1.5
Std. Dev. = 1.585
N = 224
Frequency
80
60
40
20
0
-2
0
2
4
6
8
phq_sum

D.

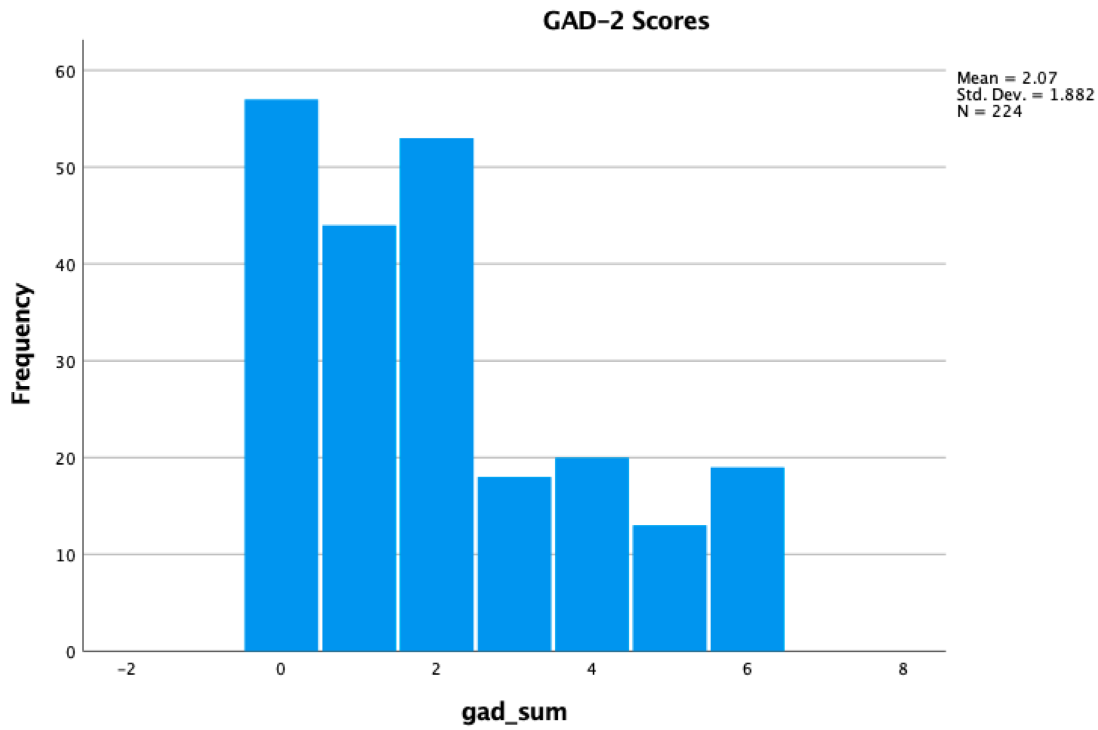


Figure 5. (A) Frequencies of scores of the BTQ. (B) Frequencies of scores of the PCL-5. (C) Frequencies of scores on the PHQ2. (D) Frequencies of scores on the GAD-2.

Table 4

Clinical Variables

Variable	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
BTQ					
valence_acc*BTQ	27.09	2	13.54	1.81	0.17
valence_int*BTQ	18.783	2	9.39	2.02	0.13
valence_edit*BTQ	11.23	2	5.62	2.45	0.09
PCL-5					
valence_acc*PCL-5	3.91	2	1.96	0.26	0.77
valence_int*PCL-5	16.567	2	8.28	1.78	0.17
valence_edit*PCL-5	7.08	2	3.54	1.54	0.22
PHQ2					
valence_acc*PHQ2	36.89	2	18.44	2.47	0.09
valence_int*PHQ2	34.98	2	17.49	3.80	**0.02**
valence_edit*PHQ2	10.73	2	5.37	2.34	0.10
GAD-2					
valence_acc*GAD-2	0.18	2	0.09	0.01	0.99
valence_int*GAD-2	9.76	2	4.88	1.04	0.35
valence_edit*GAD-2	2.08	2	1.04	0.45	0.64

On average, participants scored a 1.67 out of 6 (SD = 1.52) on the BTQ, a 19.67 out of 70 (SD = 17.60) on the PCL-5, a 1.50 out of 6 (SD = 1.59) on the PHQ2, and a

2.07 out of 6 (SD = 1.88) on the GAD-2 (Table 1). Higher scores on all four surveys indicate higher levels of trauma, depression, or anxiety. Multiple repeated measures general linear models were employed to analyze the survey scores as covariates to the valence models. The only model that predicted a significant amount of variance was the model that predicted intrusion generation from emotional valence with the PHQ-2 as a covariate, $F(2, 247) = 3.80$, $p = 0.02$ (Table 4). These findings do not support the retrieved-context theory, in that higher levels of trauma and comorbid mood disorders were not significant predictors of externalized free recall performance. This may suggest that higher trauma results more in avoidance behavior during free recall of emotional stimuli rather than intrusions. It is also possible that the pool of participants didn't allow a wide enough breadth of traumatic experience, as suggested by the low means for the survey scores.

CHAPTER 4

DISCUSSION

The current study partially supported the EEM and retrieved-context theory. Overall, positively valenced stimuli had the highest recall accuracy, the most intrusions generated, and the most successful editing of intrusions. This supports EEM in that emotional stimuli had higher recall than neutral stimuli. However, it is important to note that positive stimuli had the highest memory performance, whereas EEM states that negative stimuli tend to have greater recall success than positive. In general, the negatively valenced stimuli had surprising results. As was predicted, the negative stimuli had better recall performance and had lower editing success than the neutral stimuli. On the other hand, the negative stimuli had the lowest amount of intrusion generations. This suggests that avoidance behaviors or memory suppression may be playing a larger role than intrusive recall. Thus, the retrieved-context theory is not the only explanation for intrusive memory, and other pathways other than encoding networks need to be explored.

The lack of results in the clinical measures as predictors also suggests that trauma may result in avoidance behaviors and memory suppression over intrusive recall for emotional memory. Only the PHQ2 significantly predicted intrusion generation as a function of valence. Thus, our hypotheses of higher trauma levels resulting in higher intrusion rates and lower editing success for negative stimuli were not supported. As a result, the utilization of avoidance behaviors and memory suppression in emotional memory in PTSD should be further explored. A Think/ No-Think (TNT) task could be employed to examine these behaviors. Our lack of results may also be due to having too small of a variability in the survey scores. There is a range restriction in the survey scores, and thus our sample may not have represented the population well enough to find an effect. The choice in surveys may have also been limiting. As our sample was a pool of undergraduate students, the use of the Adverse Childhood Experience Questionnaire (ACE; Felitti, Andra, Nordenberg, Williamson, Spitz, Edwards, Koss, & Marks, 1998) may be a better measure of trauma level in a younger sample.

It is important to note that the list generation for the stimuli created some limitations to the study. Since completely unique lists were created for every study-block, serial position effects could not be examined due to being unsure of list position. This also prevented the analysis of the frequency of PLIs and ELIs, as the type of intrusion could not be identified. Lists also did not include an equal number of stimuli from each valence, and were not balanced. Because of this, the prevention of mood-induction could not be established. The consecutive presentation of three stimuli of the same valence may result in mood-induction, which can modulate encoding (Bessette-Symons, 2018).

Overall, this study replicated previous findings of the emotional enhancement of memory (Bessette-Symons, 2018; Brohawn et al., 2012; Hess et al., 2017; Murty et al., 2010; Ritchey et al., 2011; Ritchy et al., 2008). However, the lack of results in the trauma measures and low intrusion rate for negative stimuli suggest that the retrieved-context theory does not fully explain the unintentional recall of traumatic events in PTSD, or our sample was not representative of the population as a result of our measures.

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