Chapter 5

Brain Activity During Autobiographical Retrieval Is Modulated by Emotion and Vividness: Informing the Role of the Amygdala

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Additional information is available at the end of the chapter

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Abstract

Growing evidence indicates that the amygdala contributes to processing both emotional stimuli and highly vivid episodic memories. The present research used event-related potentials (ERPs) to examine the individual and joint contributions of these dimensions on the neural responses to naturalistic stimuli, namely, autobiographical memories, which vary in terms of associated emotion and the vividness of recollection. In Experiment 1, participants recalled positive and negative personal memories, and memories for which no mention of emotion was made. Events recollected with high vividness showed no effect of emotion, whereas ERPs for events recollected with low vividness differed for both positive and negative memories versus non-emotional memories. The conjoint effects of emotion and vividness reflect the correlation of these variables in everyday life: more emotional memories are more vividly recalled. In Experiment 2, we pursued the interaction of emotion and vividness by asking participants to recall negative high-arousal, negative low-arousal, and emotionally neutral memories. Processing differed by vividness but not by emotion condition. The research implies that focus on the emotional valence associated with a memory, without conjoint consideration of how vividly it is recalled, neglects a critical determinant of neural processes that are modulated by the amygdala during recall of autobiographical memories.

Keywords: amygdala, autobiographical memory, emotion, ERP, vividness

1. Brain activity during autobiographical retrieval is modulated by emotion and vividness: informing the role of the amygdala

We experience emotion at virtually every turn, often within milliseconds of a precipitating event. We also frequently re-experience the emotion when we recall the event at a later time. Emotional content contributes to the vividness of recollection [1–4]. Investigation of the neural processing associated with emotional events and experiences has a long history. For example, Lifshitz [5] and Begleiter and colleagues [6] examined event-related potentials (ERPs) in response to picture stimuli containing pleasant or unpleasant content. Numerous subsequent studies have replicated their primary finding that emotional visual scenes elicit enhanced neural processing apparent at posterior scalp sites. Patient studies and fMRI investigations have elaborated our understanding of the neural substrate involved in encoding and retrieval of emotional scenes, indicating that the amygdala plays a central role (e.g., [7–11]). Yet surprisingly, little attention has been devoted to understanding the neural processing of personal emotional situations encountered in the course of everyday life, such as annoyance at losing a parking spot in a crowded lot, winning the championship game, or losing a loved one. Moreover, although there is growing evidence that the amygdala plays a central role in processing not only emotional (e.g., [12, 13]) but also highly vivid (e.g., [1, 3]) episodic memories, there are few studies that permit articulation of the respective contributions of these aspects to memory. In the current research, in two experiments, we used event-related potentials (ERPs) to examine neural processing of personally experienced affective stimuli, namely, autobiographical memories. We examined the responses as a function of both emotional valence and vividness.

Electrophysiology has been a method of choice for studying emotion processing because of its sensitivity to real-time processing of stimuli with emotional qualities. Indeed, electrophysiological responses to emotional stimuli become apparent even prior to conscious experience of emotion. In laboratory studies of processing of stimuli with emotional qualities, including scenes, faces, and words, an "emotion effect" emerges as early as 200–300 ms after stimulus onset. The effect is apparent in slow positive-going amplitudes to emotionally valenced stimuli that continue until stimulus offset. In contrast, responses to neutral stimuli return to baseline (e.g., [14–16]). Importantly, the amplitude of the late positivity covaries with the arousal (intensity) component of emotional responses [15, 17–19]. When elicited in response to affective visual stimuli such as scenes from the International Affective Picture System (IAPS [20]), the late positivity is most pronounced on centroparietal and occipital sites and has been linked with enhanced activity in visual processing areas of the occipital cortex [15, 21]. Such findings suggest that the component reflects an up-regulation of visual perceptual processing for arousing stimuli; the up-regulation of visual perceptual processing likely contributes to the vividness of recollection (see [22] for discussion).

A major benefit of using picture and other laboratory stimuli to examine patterns of neural processing associated with emotional events and experiences and vivid recollections is the control the approach affords. Most importantly, all participants experience the same stimuli. Yet, the gain in internal validity associated with use of such stimuli comes at a cost to external validity. Specifically, the pictures, scenes, and words that are the subject of laboratory stimuli do not approximate the emotional events and vivid recollections of everyday life. As such, greater understanding of how emotion affects processing in life outside the laboratory can be gained by using stimuli that are personally relevant and significant to the participant. As well, personally relevant and significant stimuli can be expected to be associated with vivid recollections, making them ideal candidates for examining the respective roles in memory of emotion and vividness.

An excellent candidate source of stimuli that are relevant and significant to the participant is autobiographical memories (see [23] for a review). Autobiographical memories tend to be highly durable and long-lasting [24], and are accompanied by a sense of vivid reliving [25]. Because moments of great personal significance often are emotional; autobiographical memories tend to be rich in emotional content and have been shown to elicit powerful emotional responses. For example, participants recalling affectively positive or negative autobiographical events experience heightened physiological arousal, including changes in heart rate, breathing, and sweating response [26–28]. In fMRI studies, retrieval of autobiographical memories is associated with activation in emotion-related brain regions such as the amygdala and anterior cingulate cortex [29, 30]. Thus, autobiographical events and memories thereof are a potentially powerful vehicle for examining emotion processing.

Autobiographical memories also are a potentially powerful vehicle for examining neural processing involved in vivid recollection. As noted earlier, one of the characteristic features of autobiographical memories is that recollection of them is associated with a sense of vivid reliving [25]. Participants report traveling back in time as if re-experiencing the sights, sounds, and other sensory features of such events [31, 32]. Consistent with this phenomenology, in fMRI studies, retrieval of autobiographical memories is associated with activation in sensory and imagery-related regions of the brain, including posterior midline (precuneus, posterior cingulate), and visual processing (occipital cortex, ventral temporal cortex) regions (e.g., [29, 30, 33, 34]; see also [22] for a review). Thus, autobiographical memories are well suited to examination of the neural processing associated with vivid recollection.

Whereas the experiences that become autobiographical memories typically happened outside the laboratory; they can be studied in the laboratory using electrophysiology. For example, several studies have used scalp electrophysiology to study the timecourse of autobiographical retrieval, including ERP and slow cortical potential methods (e.g., [35–37]). In these investigations, participants' memories were measured as differences in the electrophysiological response to different types of retrieval cues, or for autobiographical versus imagined events. Autobiographical memories are consciously retrieved after an average of 5 seconds, yet variation in electrophysiological response related to autobiographical memory content begins as early as 400–600 ms after a retrieval cue and is associated with a negative-going slow wave on posterior sites.

In a developmental study, we extended this general approach to an ERP investigation of 7–10-year-old children's retrieval of emotional autobiographical events and experiences [38]. We elicited autobiographical memories using the cue word technique [39, 40], which has been successfully extended to children as young as 7 years of age [41, 42]. At the beginning of a laboratory visit, children were given neutral concrete nouns (cue words—e.g., *dog, chair*), and for each one, they were explicitly directed to generate a personal memory that was positive, negative, or unconstrained by emotional valence. During ERP recording, children recalled each memory in response to the visual presentation of the corresponding cue word (e.g., DOG). Because the memories were generated earlier in the laboratory visit, the children could begin recalling the memories quickly after reading the cue, allowing us to timelock autobiographical retrieval to cue onset.

The investigation revealed differential processing as a function of emotional valence of the events. In contrast with the canonical late positive potential elicited by emotional visual stimuli, recollection of autobiographical memories produced a late negative-going waveform on posterior sites (1000–1500 ms); the effect was more pronounced for positive memories relative to neutral memories [38]. Because this was the first study of its kind, and because there was no adult comparison group, it was not possible to determine the source (or sources) of the difference between the observed pattern of findings and the canonical emotion effect reported in the adult literature. The departure from the typical adult pattern could have been due to the difference in stimulus modality (internally generated autobiographical memories vs. external visual stimuli), or could relate to the developmental status of emotion processing in school-aged children (see [43], for evidence of developmental differences). For present purposes, the more important point is that the cue word technique successfully elicited differential neural processing as a function of event valence.

In the present research, we conducted two investigations of ERP responses to autobiographical memories in adults. In both experiments, we used the cue word technique to elicit autobiographical memories. In Experiment 1, in advance of their laboratory visits, participants received a list of neutral concrete nouns (cue words) and were explicitly directed to generate personal memories to accompany each word. As in Ref. [38], some of the trials were unconstrained as to the valence of the memory to be retrieved, whereas others explicitly prompted recall of a positive or negative personal memory. During ERP recording, participants recalled each memory in response to the visual presentation of the corresponding cue word. They also rated their recollections of the events in terms of their vividness.

To anticipate the results of Experiment 1, we observed differential processing of positive relative to negative autobiographical memories as early as 400 ms. In comparison with the traditional "emotion effect," ERP responses to positive and unconstrained memories did not differ; both elicited more positive-going slow-wave responses relative to negative memories. Importantly, the emotion effect both interacted with and became more canonical when we took into account the reported vividness of the recollection. On trials on which participants reported highly vivid recollections, there was no effect of emotion. In contrast, on trials on which participants reported less vivid recollections, ERPs responses to both positive and negative events differed from those to emotionally unconstrained events.

To further pursue the joint effects of emotion and vividness, in Experiment 2, we focused on negative memories, and manipulated the level of arousal associated with them. Specifically, participants were explicitly instructed to recall negative autobiographical memories with different levels of arousal, based on the circumplex model of emotion [44]: low-arousal and high-arousal. That is, participants were instructed to recall events during which they experienced sadness, guilt, or loneliness (low arousal), and during which they experienced fear, anxiety, or anger (high arousal). On the balance of the trials, participants were instructed to recall events and experiences that were explicitly neutral in valence. We expected this manipulation to result in a stronger contrast between the emotion conditions and the non-emotion condition, relative to the unconstrained "neutral" condition in Experiment 1. The manipulation also permitted test for replication of the effects of vividness observed in Experiment 1.

From the standpoint of eliciting processing of emotion, using cue words to elicit autobiographical memories is ideal. First, autobiographical memories represent rich, naturalistic emotion stimuli, thus facilitating extension of our knowledge of emotional neural processing beyond the more typical laboratory scenario in which participants view a series of static visual stimuli. Second, in contrast with picture or word stimuli, memories are tailored to the individual participant and entail greater personal relevance. They also typically are associated with recollections that vary in their subjective vividness. Third, because the affective content and sources of vividness are internally generated, low-level stimulus confounds are reduced relative to the more common emotion-elicitation methods (e.g., pictures, scenes) for which the content is external. We further reduced confounding neural activity relating to the content of the retrieval cues by using affectively neutral cue words, which, across participants, were each assigned equally often to the different emotion conditions (positive, negative, and unconstrained in Experiment 1; negative high-arousal, negative low-arousal, and neutral in Experiment 2).

The current examination of emotional autobiographical memories represents an important extension of the literature on emotion processing, testing the extent to which "emotion effects" observed in previous ERP studies represent core elements of the emotional response, which generalize beyond emotions elicited by impersonal, external stimuli, to emotions associated with self-relevant, internally generated stimuli. Moreover, the examination permits assessment of the extent to which patterns of ERP activity associated with different emotion conditions are qualified by the vividness of recollection. Given that the amygdala plays a central role in processing both emotional (e.g., [12, 13, 45, 46]) and highly vivid [1, 3] episodic memories, there is reason to expect that both factors will influence neural responses.

2. Experiment 1

2.1. Method

2.1.1. Participants

Forty-six adults (23 women) age 18–28 years (M = 20.8 years) participated. Fifty-two percent of participants were Caucasian, 20% were African-American, 20% were Asian, 2% were of mixed race, and 7% did not indicate their race. The data from all participants were included in analyses of the behavioral data. The data from 39 participants (20 women) were included in analyses of the ERP data; seven participants were excluded from ERP analyses because of excessive noise or artifact in their ERP data (See Section 2.1.3). Participants were compensated with either class credit or a gift certificate. The paradigm was reviewed and approved by the university Institutional Review Board.

2.1.2. Stimuli, materials, and procedure

The study involved elicitation of memories using cue words via an online survey, and a laboratory session during which event-related potentials (ERPs) were recorded while participants viewed cue words on a computer screen and retrieved the corresponding memories.

2.1.2.1. Elicitation of memories with an online survey

Five to seven days in advance of their laboratory visit, participants were e-mailed a direct link to a secure and encrypted online survey that was designed and managed using SurveyMonkey (www.surveymonkey.com). The first page of the survey outlined the study and its requirements and informed participants that by proceeding, they were consenting to participate in the study.

The survey consisted of 90 neutral concrete nouns that were selected from previous studies [e.g., 38, 40–42] and used as cue words. A complete list of cue words is given in Appendix A. The 90 words were used to elicit affectively negative and positive memories, as well as memories unconstrained as to emotional valence. Each participant selected 75 of the 90 words and described a memory for each word: 25 positive, 25 negative, and 25 neutral. Three different surveys were created so that each word was used in each emotion condition approximately equally often across participants (e.g., the cue word *paper* was used to elicit positive, negative, and unconstrained memories in equal numbers of participants). To aid in later recall (see below), participants also provided an additional keyword or phrase that would remind them of the target event. The additional keywords were restricted to 1–3 non-emotion words and typically represented a specific element of the event such as a person's name (e.g., Night and *Jessica*), the location of the memory (e.g., Night and *Las Vegas*), or what they were doing (e.g., Night and *Mini Golf*).

In the survey, the 90 cue words were divided into 15 sets of six words each. For each set of six words, participants were instructed to select five words and describe one specific event that occurred within the past year that related to the given word (e.g., for the word *dog:* "Last weekend I took my dog on a walk through the park"). This design allowed participants to select any combination of five words that were more easily associated with specific memories, and exclude the sixth. Participants were prompted to select events from the past year to control the age of memories across the different emotion conditions, while still allowing participants to select from a range of remembered events. The first five sets of words elicited memories without any mention of emotion. Responses to these unconstrained prompts constitute the *unconstrained* condition. Every set that followed alternated between the *negative* and *positive* conditions (i.e., sets 1–5 were unconstrained, sets 6, 8, 10, 12, and 14 were negative, and sets 7, 9, 11, 13, and 15 were positive). The survey began with the unconstrained prompt in order to omit information about emotion from the instructions, allowing participants to

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select memories in a manner unconstrained by emotion. The survey always ended with a set of positive memories so that participants ended the experience on a positive note.

For the unconstrained condition, participants were given the general prompt: “There are six words given below. Choose any FIVE of the words and describe an event of which each word reminds you.” Participants were further instructed to describe the event in two to four sentences. For the negative condition, participants were given the more specific prompt: “There are six words given on the next page. Choose any FIVE of the words and describe a NEGATIVE event of which each word reminds you. These should be events when you felt UNHAPPY, ANGRY, SAD or UPSET.” The instructions in the positive condition prompted participants to describe events when they felt “HAPPY, EXCITED, CHEERFUL or GLAD.”

After writing a description and determining the additional keyword for an event, participants were asked to indicate the pleasantness of their emotional response thinking about the event now (i.e., while completing the survey). The rating was on a five-point scale, ranging from −2 (very unpleasant), to 0 (neutral), to 2 (very pleasant). Additionally, participants were asked to indicate their arousal by rating the intensity of their emotional response (a) “when the event first happened” and (b) “as you think about the event now.” These ratings were on a five-point scale from 1 (no emotional response) to 5 (strong emotional response). Sample narratives are provided in Appendix B. The survey took approximately 2–3 hours to complete.

2.1.2.2. Review of events and retrieval of memories while recording event-related potentials (ERPs)

An average of 2 days after completing the online survey, participants visited the laboratory during which they were (a) interviewed by a researcher to review the memories provided on the survey and (b) retrieved the memories during collection of ERP data. Before the session began, participants gave informed written consent to participate in the ERP portion of the study. During the interview, participants were seated in a chair directly across from a researcher. One by one, the researcher gave the participant a cue word from the survey along with the additional keyword the participant herself or himself provided, and the participant briefly summarized the event as s/he had described on the survey. In most cases, participants confirmed in free recall that the memory was of one specific event. If that information was not provided, the researcher explicitly asked the participant for confirmation. If the memory was not specific, the researcher prompted the participant to narrow in on a specific element of the event. Additionally, if the keyword that the participants provided was emotional (e.g., “scared” or “happy”), the experimenter guided the participant in the selection of a neutral keyword to replace it.

While participants reviewed their memories with one researcher, two additional researchers applied an Advanced Neuro Technology (A.N.T.) WaveGuard 32-channel ERP cap (A.N.T. Software B.V., Enschede, The Netherlands). The elastic-lycra cap contained 32 electrodes placed according to the International 10–5 system, an adaptation of the International 10–20 system [47]. For all participants, impedances were between 0 and 10 kΩ, and most frequently below 5 kΩ. The data were referenced online to mathematically linked mastoids. Using ASA amplifier (A.N.T. Software B.V., Enschede, the Netherlands), the EEG data were sampled at 256 Hz continuously and amplified 20,000 times. The interview and application of the ERP cap took 20–40 minutes to complete.

Immediately after the interview and capping, participants were seated approximately 60 cm from a 38-cm computer monitor where the ERP stimuli were presented. Participants silently engaged in autobiographical recollection in response to cue words. Individual cue words were shown at the center of a slide, and the participant's additional keyword(s) was shown directly below the cue word. Words were presented in black, size 54 Calibri font on a blue background. The cue word and additional keyword pair occupied approximately 0.8–2.5° × 1.25° of the visual field on either side of the visual midline. Trials were structured as follows (also see **Figure 1**). Participants first viewed the cue and keywords, displayed for 3000 ms. During this time, participants were instructed to recall the corresponding autobiographical memory: "Think about who was there, what you were feeling, and generally try to recreate the event in your mind." Participants then rated the vividness of their memory on a scale from 0 to 3 (0 = not recalled, 3 = high vividness) using a button box corresponding to the visual scale. The vividness scale was displayed for 3000 ms. This was followed by a fixation cross, displayed for 3000 ms, during which participants were instructed to clear their minds, stop thinking about the previous event, and prepare for the next cue word. A jittered inter-stimulus interval (blank screen) of 300–400 ms followed the recall and rating portions of the trial.

Before beginning ERP data collection, participants were shown two practice trials to orient them to the timing of the task, and the button press. During the ERP presentation, words were presented quasi-randomly, with no more than three words of the same emotion in sequence. Each word was shown twice (all 75 words were shown, and then the presentation was repeated) for a total of 150 trials, with 50 trials in each affective valence condition (25 individual memories per condition). Two ERP orders for each of the three surveys were created in this fashion (six orders total), and counterbalanced across participants. The full ERP data collection took approximately 25 minutes.

2.1.3. Electrophysiological data reduction

The raw EEG data were individually bandpass filtered (0.1–30 Hz, roll-off of 24 decibels/octave). Electrodes with off-scale measurements were removed prior to averaging, and

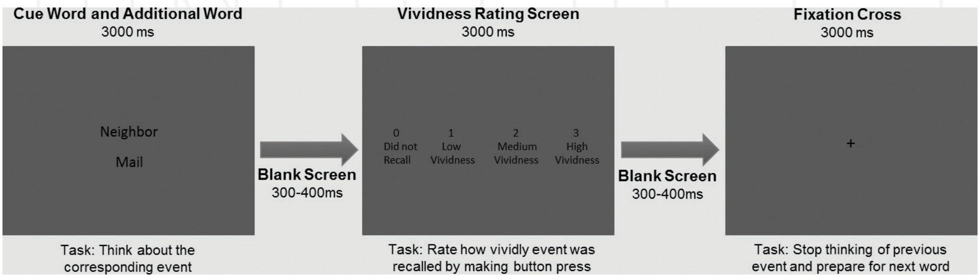

Figure 1. Structure of stimulus presentation for a sample ERP trial.

excluded from analysis. No more than two electrodes were removed from any one participant's data (max loss = 6.25% of total electrodes), and electrodes were removed in hemisphere-matched pairs (e.g., if T7 was removed, T8 also was removed). Data from discarded electrode sites were not replaced. Eye-blink, saccade, and muscle artifacts were removed by independent component analysis using EEGLAB 13.4.4b ([48] http://www.sccn.ucsd.edu/eeglab) running under Matlab 8.4.0 (MathWorks, Natick, MA, USA). Additional artifacts that exceeded ±150 μV (typically caused by excessive movement or muscle activity) were excluded as well. Data were referenced to a 200 ms pre-stimulus baseline. Participants were included in final data averaging if at least 50% of their trials were usable (i.e., at least 25 trials per condition, $M = 47$ trials). These procedures resulted in exclusion of data from seven participants. Across participants, we created separate grand averages for trials in the positive, negative, and unconstrained conditions.

3. Results

3.1. Preliminary analyses

In preliminary analyses, we examined both the behavioral (pleasantness, arousal, and vividness) and ERP data for systematic effects associated with participants' gender. None was found. Therefore, gender was not included as a factor in the main analyses.

3.1.1. Behavioral data

We used within-subjects analyses of variance (ANOVAs) to test whether positive or negative memories differed from unconstrained memories in subjective pleasantness, arousal, and vividness. Post-hoc contrasts between emotion pairs were Bonferroni-corrected for multiple comparisons. Descriptive statistics are provided in **Table 1**.

3.1.1.1. Pleasantness

Average ratings of pleasantness varied significantly by emotion condition, $F(2, 88) = 456.17$, $p < 0.001$. Positive memories were rated as more pleasant than unconstrained ($p < 0.001$) and negative memories ($p < 0.001$). Unconstrained memories were rated as more pleasant than negative memories ($p < 0.001$). The ratings suggest that the emotional content of participants' memories was consistent with the target emotion.

3.1.1.2. Arousal

Average ratings of arousal at the time of the remembered event ("Arousal then") varied significantly by emotion condition, $F(2, 88) = 11.18$, $p < 0.001$. Positive and negative memories were rated as more arousing than unconstrained memories (ps < 0.0001); positive and negative memories did not differ ($p = 0.73$). Arousal when recalling the memory during the online survey ("Arousal now") also varied by emotion condition, $F(2, 88) = 9.02$, $p < 0.001$.

Scale/valence condition	Experiments				
	Experiment 1			Experiment 2	
	M	SD		*M*	SD
Pleasantness (scale −2 to +2)			Pleasantness (scale −2 to +2)		
Negative	−1.08	(0.05)	High-arousal negative	−0.93	(0.35)
Positive	1.14	(0.05)	Low-arousal negative	−0.83	(0.29)
Unconstrained	0.22	(0.05)	Neutral	0.14	(0.22)
Arousal (then) (scale 1–5)			Arousal (then) (scale 1–9)		
Negative	3.66	(0.09)	High-arousal negative	5.53	(1.61)
Positive	3.69	(0.07)	Low-arousal negative	4.60	(1.67)
Unconstrained	3.42	(0.07)	Neutral	2.49	(1.63)
Arousal (now) (scale 1–5)			Arousal (now) (scale 1–9)		
Negative	2.64	(0.10)	High-arousal negative	3.10	(1.41)
Positive	2.92	(0.09)	Low-arousal negative	2.91	(1.31)
Unconstrained	2.68	(0.07)	Neutral	1.84	(1.27)
Vividness (scale 0–3)			Vividness (scale 0–3)		
Negative	2.15	(0.06)	High-arousal negative	2.33	(0.39)
Positive	2.31	(0.06)	Low-arousal negative	2.23	(0.39)
Unconstrained	2.39	(0.05)	Neutral	2.17	(0.47)

Table 1. Subjective ratings of pleasantness, arousal, and vividness for autobiographical memories.

Positive memories received higher arousal ratings than unconstrained ($p = 0.001$) and negative ($p = 0.001$) memories. Unconstrained and negative memories did not differ ($p = 0.51$).

3.1.1.3. Vividness

After each ERP trial, participants indicated the vividness of their recollection of the cued event. The emotional valence of the memories was related to their vividness ratings, $F(2, 88) = 31.04$, $p < 0.001$. Unconstrained memories were rated as more vividly recalled than positive memories ($p = 0.005$); positive memories were more vividly recalled than negative memories ($p < 0.001$).

3.1.2. ERP data

Motivated by previous studies that found emotion effects on the ERP slow wave, we analyzed the mean amplitude of slow wave responses to the memory stimuli. We examined the mean amplitude of the slow wave within 400–1000 ms, and the mean amplitude of the sustained slow wave within 1000–2000 ms. Consistent with previous studies of emotion processing [14, 15, 17], visual inspection suggested that emotion effects were strongest on centroparietal and posterior lateral sites. Emotion effects were therefore quantified for posterior lateral (P3, P4, P7, P8) and centroparietal (CP1, CP2, CP5, CP6) clusters. In the analyses to follow, for violations of sphericity, we applied Greenhouse-Geisser correction to the *p*-value. Post-hoc contrasts between emotion pairs were Bonferroni-corrected for multiple comparisons.

3.1.2.1. Analysis by emotion condition

We analyzed ERP amplitudes using separate mixed-effects 3 (emotional valence of memories: positive, negative, unconstrained) × 2 (cluster: posterior lateral, centroparietal) × 2 (hemisphere: left, right) analyses of variance (ANOVAs) for the slow wave (400–1000 ms) and sustained slow wave (1000–2000 ms) windows. The overall waveform is illustrated in **Figure 2**. Given the focus of the analysis on emotion, we report only main effects and interactions involving emotional valence of memories.

As suggested by **Figure 2**, emotional valence significantly influenced mean amplitude during the slow wave window (400–1000 ms) across electrode sites and hemispheres, $F(2, 76) = 4.17$, $p = 0.019$. The mean amplitude for negative memories was less positive-going than for positive memories ($p = 0.025$, $M_{diff} = -0.479$); the difference between negative and unconstrained memories approached significance ($p = 0.064$, $M_{diff} = 0.390$). Positive and unconstrained memories did not differ ($p = 1.00$, $M_{diff} = 0.089$).

There was not an emotional valence effect in this sustained slow wave window (1000–2000 ms; $p = 0.749$). Thus beyond 1000 ms, there was no evidence that emotion influenced sustained processing on centroparietal and posterior lateral sites. In fact, there were no statistically significant effects in the sustained slow wave window.

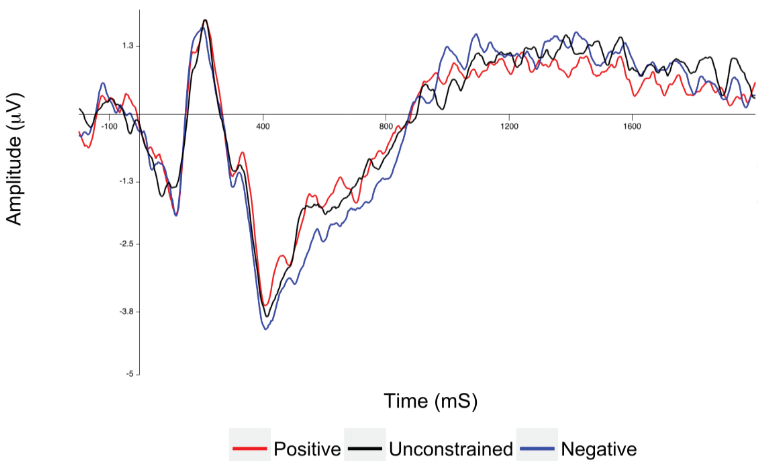

Figure 2. ERPs as a function of emotion condition (positive, negative, unconstrained) in Experiment 1.

3.1.2.2. Analysis by vividness

We analyzed ERP amplitudes using mixed-effects 2 (vividness: high [rating of 2 or 3], low [rating of 0 or 1]) × 3 (emotional valence of memories: positive, negative, unconstrained) × 2 (cluster: posterior lateral, centroparietal) × 2 (hemisphere: left, right) analyses of covariance (ANCOVAs), which took into account differences in trial counts for high- and low-vividness trials. We conducted separate ANCOVAs for the slow wave (400–1000 ms) and sustained slow wave (1000–2000 ms) windows. As above, given the focus of the analysis on vividness, we report only main effects and interactions involving subjective vividness of recollection.

In the slow wave window (400–1000 ms), although the main effect of vividness was not statistically significant ($p = 0.292$), vividness of recollection significantly interacted with cluster, $F(1, 38) = 29.75$, $p < 0.0001$. However, separate one-way ANCOVAs for each cluster (posterior lateral, centroparietal) revealed no effects of vividness.

Vividness also interacted with hemisphere, $F(1, 38) = 9.75$, $p < 0.003$; the two-way interaction was further qualified by the three-way interaction with emotion, $F(2, 76) = 3.40$, $p = 0.038$. To examine the interaction, we conducted separate ANOVAs for each level of vividness. As suggested by the top panel of **Figure 3**, for trials on which participants reported highly vivid recollections, there was no effect of emotion ($p = 0.915$). Although the interaction of

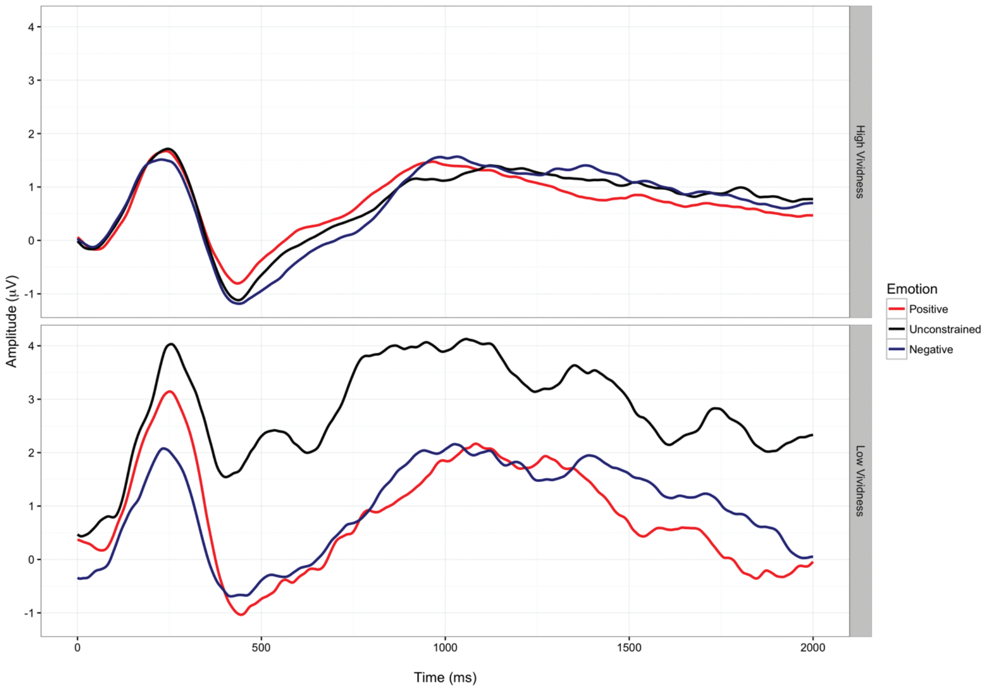

Figure 3. ERPs as a function of vividness in Experiment 1, for high-vividness trials (top panel) and low-vividness trials (bottom panel).

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emotion × hemisphere was significant, $F(2, 76) = 3.66$, $p = 0.030$, follow-up analyses revealed no emotion effects. For trials on which participants reported less vivid recollections, the main effect of emotion was significant, $F(2, 76) = 3.12$, $p < 0.05$. As suggested by the bottom panel of **Figure 3**, the mean amplitudes for emotional events—both positive and negative—were less positive, relative to unconstrained events ($M_{diff} = 1.043$ and 1.331, for positive vs. unconstrained and negative versus unconstrained, respectively; ps < 0.0001); mean amplitudes did not differ for positive and negative memories ($M_{diff} = 0.288$).

In the sustained slow wave window (1000–2000 ms), ANCOVA revealed a three-way interaction of vividness × cluster × hemisphere, $F(1, 38) = 4.45$, $p = 0.041$. Separate analyses by cluster revealed no significant effects in the centroparietal cluster. In the posterior lateral cluster, the interaction of vividness × hemisphere was significant, $F(1, 38) = 4.93$, $p = 0.032$. Over the right hemisphere, there was no effect of vividness. Over the left hemisphere, amplitude was more positive for high versus low vividness recollections ($M_{diff} = 1.222$), though the effect only approached statistical significance ($p = 0.14$).

4. Discussion

The primary goal of Experiment 1 was to use ERP's to examine the processing of autobiographical memories that varied in emotional valence and for which recollection varied by vividness. Based on their ratings, participants retrieved autobiographical memories that were positively valenced, negatively valenced, and more neutral in content, and which were differentially vivid.

As predicted, the emotional content of the memories influenced ERP responses, though the effect was short-lived and not entirely in line with the patterns observed in prior studies of external stimuli, such as stimuli from the IAPS. In the slow wave window (400–1000 ms), negative memories evoked less positive-going responses than positive memories. The difference between negative and unconstrained memories approached significance. In the sustained slow wave window (1000–2000 ms), no effects of emotion were observed. The patterns differed from the typical late positive emotion effects observed in previous studies. Commonly, the emotion effect in ERP is manifest as a slow wave that is more positive-going for emotional than neutral stimuli (e.g., [14–16, 21]). One likely source of the difference is the study design, in which we recorded ERPs to internally generated, personally relevant stimuli, in contrast to external, visual stimuli. Moreover, ERPs were recorded as participants recalled emotional events versus the more typical study design involving recognition. The departures from the canonical emotion effect in the literature suggest that the stimulus characteristics and retrieval conditions are critical in understanding emotion effects in neural processing, and thus some limits to the generalizability of previously identified emotion effects.

Analysis of the data considering the vividness of recollection as well as the emotional valence revealed another likely source of difference between the findings of the present research and previous studies in the literature. Specifically, for highly vivid recollections, there was no effect of emotion condition. In contrast, on trials on which recollection was rated as less vivid, ERPs to both positive and negative memories differed from those to unconstrained memories.

This pattern is a more typical "emotion effect," yet as noted above, ERPs to explicitly emotional memories were less positive, relative to unconstrained memories. The fact that the effect was only observed on low-vividness trials suggests that emotion and vividness may have additive effects on slow-wave amplitudes, effects that are not observed when vividness is at ceiling. The conjoint effect of emotion and vividness reflects the natural correlation of these variables in everyday life: more emotional memories are more vividly recalled.

One source of concern with the present research is that the comparison of memory for emotional stimuli to non-emotional stimuli was made not to a "neutral" stimulus category, but to a category "unconstrained" as to emotion. That is, there was no explicit mention of the emotional valence of the memories nominated in it. As intended, the valence of the memories featured in this category was intermediate between positive and negative, based on participants' ratings. However, participants' ratings also indicated that at the time of the memory report, the level of arousal associated with the unconstrained memories was not significantly lower than that associated with the negative memories. Moreover, at the time of the ERP recording, participants rated the vividness of their unconstrained memories as higher than both positive and negative. These features of the memories in the unconstrained category may have diminished differences in the neural processing of the stimuli, relative to explicitly emotionally valenced stimuli.

In Experiment 2, we extended the study of neural processing of emotional autobiographical memories, as well as addressed the limitations of Experiment 1. Specifically, we further investigated the potential additive effects of emotion and vividness, testing for replication of the effect of vividness on the slow-wave amplitudes in response to emotional memories. We also replaced the unconstrained condition with a condition that was explicitly affectively neutral. Participants were explicitly instructed to nominate memories of events during which they did not experience emotion. Further, we focused on events that were negative, and did not include positive emotional events. Exclusive focus on negative events is common in the emotion processing literature, and inclusion of positive stimuli in Experiment 1 may be one reason why the emotion effects were somewhat muted, relative to the literature as a whole. We included two classes of negative emotional stimuli, namely, low-arousal and high-arousal [44]. That is, participants were instructed to recall events during which they experienced sadness, guilt, or loneliness (low arousal), and during which they experienced fear, anxiety, or anger (high arousal). We anticipated that this manipulation would increase the opportunity for detection of differences between negative and neutral memories.

5. Experiment 2

5.1. Method

5.1.1. Participants

Forty-nine individuals (25 women) age 16–22 years (*M* = 19.8 years) participated. Forty-eight of the participants gave written informed consent to take part in this study. For the 16-year-old, consent was obtained from a legal guardian. Thirty-eight percent of participants were

Caucasian, 18% were African-American, 36% were Asian, 6% were of mixed race, and 4% did not indicate their race. Two additional participants were excluded from analyses of the behavioral data because the length of the delay between phases of the experiment exceeded limits. Six additional participants were removed from ERP analyses due to (a) excessive noise in the ERP data ($N = 5$) or (b) a technical malfunction prevented the recording of electrophysiological data ($N = 1$). Participants were drawn from the same source and represent the same population as in Experiment 1. None of the participants had taken part in Experiment 1. Participants received either class credit or a gift certificate. The paradigm was reviewed and approved by the university Institutional Review Board.

5.1.2. Stimuli, materials, and procedure

The study consisted of the same two phases as in Experiment 1. In each phase, the procedure was the same as in Experiment 1, except as noted.

5.1.2.1. Elicitation of memories in response to cue words with an online survey

An average of 7 days before their lab visit, participants were e-mailed a direct link to a secure and encrypted online survey. The survey consisted of 84 neutral concrete nouns that overlapped with those used in Experiment 1 (which featured 90 potential cue words). The 84 words were used to elicit autobiographical memories that were affectively neutral, negative low-arousal (including emotions such as sadness, guilt, and loneliness), and negative high-arousal (including emotions such as fear, anxiety, and anger). Participants were instructed to select 54 of the 84 words and described a memory for each word: 18 neutral, 18 negative low-arousal, and 18 negative high-arousal. Each cue word was used in each emotion condition approximately equally often across participants. As in Experiment 1, participants also provided an additional keyword or phrase to facilitate later recall. The additional keywords were restricted as in Experiment 1.

In the survey, the 84 cue words were divided into 12 sets of seven words each. In the first six sets, participants were instructed to select five of the seven words, and describe one specific event that occurred within the past year that related to the given word. In the last six sets, participants were instructed to describe memories for four of the seven words.

For each set of words, participants were instructed to describe memories of one emotion condition. For the negative low-arousal condition, the prompt was: “This set of memories should be about emotionally negative events during which you felt SADNESS, LONELINESS, FAILURE, DISAPPOINTMENT, or GUILT.” For the negative high-arousal condition, the prompt was: “This set of memories should describe emotionally negative events during which you felt ANGER, FEAR, DISGUST, ANXIETY, or HATRED.” For the neutral condition, the prompt was: “Neutral memories should describe emotionally neutral events during which you felt NO SADNESS, NO ANGER, NO ANXIETY, NO HAPPINESS, and NO PRIDE.” To further emphasize the distinctions, participants were also instructed to: “try to avoid describing events during which you were feeling emotions from more than one category.”

After writing a description and determining the additional keyword for each cue word, participants rated the pleasantness of their emotional response and their level of arousal at the time of the event and at the time of the survey. As in Experiment 1, pleasantness of the emotional response thinking about the event now (i.e., while completing the survey) was rated using the five-point scale (−2 [very unpleasant], 0 [neutral], 2 [very pleasant]). Whereas in Experiment 1, participants used a five-point scale to rate their level of arousal, in the present experiment, we expanded the range to nine points: 1 (little or no arousal) to 9 (extremely aroused). The entire survey took approximately 2–3 hours to complete.

5.1.2.2. Review of events and retrieval of memories while recording event-related potentials (ERPs)

As in Experiment 1, after an average two-day delay, participants took part in a laboratory visit that began with an interview to review the memories provided in the survey. The interview was conducted following the same procedures as outlined in Experiment 1. While participants reviewed their memories with one researcher, two additional researchers applied the ERP cap. The ERP hardware, software, and settings were the same as used in Experiment 1. Stimulus presentation, recording, and vividness ratings (0 = not recalled, 3 = high vividness), also was the same as in Experiment 1. One exception was that whereas in Experiment 1, each cue word was presented two times, in the present experiment, each cue word was presented three times (i.e., all 54 words were shown, and then the presentation was repeated two additional times) for a total of 162 trials, with 54 trials in each condition. Two ERP presentation orders for each of the three surveys were created in this fashion (six orders total), and counterbalanced across participants. To ensure that the session ended on a positive note, after all the cue words were presented, participants were shown 10 positively valenced images from the International Affective Picture System (IAPS) and were instructed to rate each photo on a four-point scale (0 = very unpleasant, 3 = very pleasant). These ratings were not analyzed. ERP data collection took roughly 25 minutes.

5.1.3. Electrophysiological data reduction

Data reduction procedures were the same as in Experiment 1. Participants were included in final data averaging if at least 50% of the trials from the first two presentations were usable (i.e., at least 27 of 54 trials in each condition, M = 52 trials). Across participants, we created separate grand averages for trials in each condition.

6. Results

6.1. Preliminary analyses

As in Experiment 1, we examined the behavioral (pleasantness, arousal, and vividness) and ERP data for effects associated with participant gender. None was found. Therefore, gender was not included in the main analyses.

6.1.1. Behavioral data

We used within-subjects analyses of variance (ANOVAs) to test whether memories of low- and high-arousal negative events significantly differed from neutral events, and each other, in terms of reported pleasantness, emotional arousal, and vividness. Post-hoc contrasts between emotion pairs were Bonferroni-corrected for multiple comparisons. Descriptive statistics are provided in **Table 1**.

6.1.1.1. Pleasantness

Participants rated the pleasantness of their memories differently as a function of emotion condition, $F(2, 94) = 305.38$, $p < 0.001$. Post-hoc tests revealed that pleasantness ratings significantly differed between all conditions such that negative high-arousal events were rated as less pleasant than both negative low-arousal ($p = 0.02$) and neutral events ($p < 0.001$), and that negative low-arousal events were rated as less pleasant than neutral events ($p < 0.001$).

6.1.1.2. Arousal

Participants' ratings of emotional arousal at the time the remembered event occurred varied significantly by emotion condition, $F(2, 94) = 107.86$, $p < 0.001$. Arousal levels significantly differed between all conditions such that negative high-arousal events were rated as more arousing than negative low-arousal events ($p < 0.001$); negative low-arousal events were rated as more arousing than neutral events ($p < 0.001$). Emotional arousal when recalling the event during the online survey also varied by emotion condition, $F(2, 94) = 48.07$, $p < 0.001$. The same pattern was observed, such that negative high-arousal events were rated as more arousing than negative low-arousal events ($p = 0.04$); negative low-arousal events were rated as more arousing than neutral events ($p < 0.001$).

6.1.1.3. Vividness

After each ERP trial, participants indicated the vividness of their recollection of the cued event. The emotional valence of the memories significantly influenced vividness ratings, $F(2, 94) = 5.10$, $p = 0.008$. Post-hoc tests revealed that that negative high-arousal event memories were rated as more vivid than both negative low-arousal and neutral event memories, respectively ($p = 03$; $p = 0.003$). The negative low-arousal and neutral memory conditions did not significantly differ from each other in terms of vividness ($p = 0.76$).

6.1.2. ERP data

As in Experiment 1, in analysis of the ERP data, for violations of sphericity, Greenhouse-Geisser correction was applied to the p-value. Post-hoc contrasts between emotion pairs were Bonferroni-corrected for multiple comparisons.

6.1.2.1. Analysis by emotion condition

We first conducted analyses parallel to those for Experiment 1, with emotion condition (negative high-arousal, negative low-arousal, neutral), cluster, and hemisphere as factors. ERP amplitudes for the different emotion conditions are reflected in **Figure 4**. Although there was some variability in ERP amplitude as a function of emotion condition, effects of emotion condition were not statistically significant in either the 400–1000 ms window, $F(2, 88) = 0.242$,

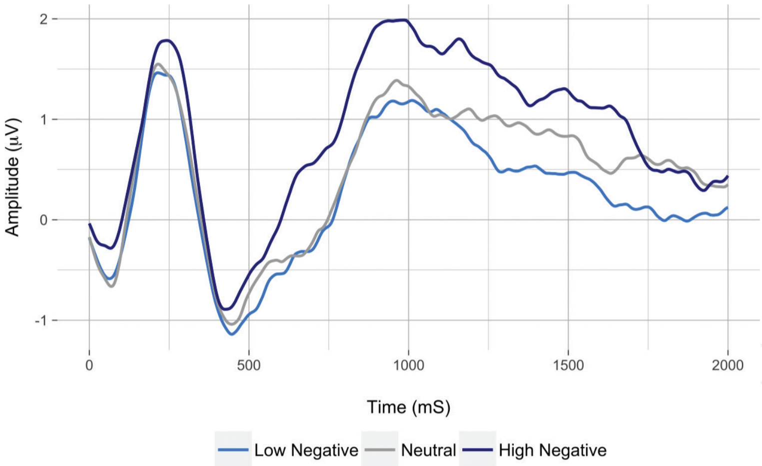

Figure 4. ERPs as a function of emotion condition (negative high-arousal, negative low-arousal, neutral) in Experiment 2.

$p = 0.785$, or the 1000–2000 ms window, $F(2, 88) = 0.332$, $p = 0.718$. There were no significant interactions with emotion condition.

6.1.2.2. Analysis by vividness

As in Experiment 1, we divided the data into high (ratings of 2–3) and low (ratings of 0–1) vividness. We then examined ERP amplitudes in mixed-effects 2 (vividness: low, high) × 3 (emotional valence of memories) × 2 (cluster) × 2 (hemisphere) ANCOVAs, which took into account differences in trial counts for high- and low-vividness trials. Separate ANCOVAs were conducted for the slow wave (400–1000 ms) and sustained slow wave (1000–2000 ms) windows. As in Experiment 1, given the focus of the analysis on vividness, we report only main effects and interactions involving subjective vividness of recollection.

In the slow wave window (400–1000 ms), the analysis did not reveal a main effect vividness ($p = 0.124$), yet the interaction of vividness × cluster was significant, $F(1, 44) = 44.839$, $p < 0.0001$. Follow-up analyses revealed an effect of vividness in the posterior lateral cluster, $F(1, 44) = 4.407$, $p = 0.041$. ERP amplitude was significantly greater on high-vividness trials ($M = 0.605$) relative to low-vividness trials ($M = 0.203$; $M_{diff} = 0.402$). In contrast, in the centroparietal cluster, there was not a significant difference as a function of the vividness of the recollection ($p = 0.321$). Emotion did not emerge as a significant effect nor participate in any interactions.

In the sustained slow wave (1000–2000 ms), the only significant effect was the interaction of vividness × cluster, $F(1, 44) = 4.822$, $p = 0.033$. Follow-up analyses did not reveal effects of vividness in either cluster.

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7. Discussion

As in Experiment 1, the conditions of the present experiment resulted in retrieval of autobiographical memories that differed in pleasantness, arousal at the time of the experience and at the time of recollection, and the vividness of recollection. In all cases, negative high-arousal memories were rated as having more of the attributes relative to negative low-arousal and neutral memories. In spite of the success of the manipulation, ERPs to the stimuli did not differ by emotion condition.

Whereas ERPs did not differ by emotion condition, they did differ by vividness. In the slow-wave window (400–1000 ms), memories that were rated as vividly recollected had greater mean amplitudes relative to memories that were rated as less vividly recollected. As was the case for Experiment 1, this pattern of findings implies that what is frequently referred to as the "emotion" effect may in some cases (such as the present research) more appropriately be described as a vividness effect. The effect emerges in response to emotional stimuli because memories of such stimuli typically are evoked with high levels of vividness. Yet when the contributions of emotion and vividness are jointly considered, the vividness of the recollection, rather than the emotion associated with the event, explains the greater amount of variance.

8. General discussion

Use of electrophysiology to examine neural responses to emotional stimuli has a long history [5, 6] revealing differential processing by emotion condition [12, 45]. Studies with patient populations and with fMRI have elaborated the findings, implying that the amygdala plays a central role in processing of emotion (e.g., [7–9]). More recently, the amygdala also has been implicated in memories that are subjectively rated as high on vividness [1, 3]. In the present research, we furthered these literatures, examining event-related potentials (ERPs) to stimuli that are both emotional and vividly recollected, namely, autobiographical memories. The findings revealed effects associated with both dimensions of difference.

In the present research, we used autobiographical memories as stimuli because they are personally relevant and significant to the participant. They also frequently are about emotional events that are recollected with varying degrees of vividness (e.g., [22], for discussion). As such, they could be expected to inform emotion effects as they occur in life outside the laboratory. We elicited the emotional autobiographical memories using neutral cue words. Neutral cue words provide an advantage relative to the more common methods of emotion elicitation via picture stimuli, short film clips, or words. The cue word stimulus itself is neutral, and across participants, the same word can be used equally often as a cue for memories from difference valence categories (see Appendix B, for example). This ensures that any effects specific to individual cue word stimuli are diminished after averaging across participants. In contrast, picture, word, and film stimuli all confound emotion condition with content (see [38] for discussion).

The unique methodology of the present research revealed unique patterns of neural processing. In Experiment 1, we observed differential processing of positive relative to negative autobiographical memories as early as 400 ms. In contrast to the canonical "emotion effect," ERP responses to positive memories did not differ from non-emotional memories; non-emotional memories did not differ from negative memories, though the effect approached significance (p = 0.064). In Experiment 2, in which we contrasted recall of negative high-arousal, negative low-arousal, and neutral memories, there were no effects of emotion. Similar patterns of processing of emotional and neutral memories were observed in spite of the fact that participants rated their memories as differentially pleasant and as associated with different levels of arousal. We speculate that the use of an explicitly "neutral" condition in Experiment 2 may have been responsible for the dampening of differences between valence conditions. Although participants were instructed to recall events that were not emotional, by virtue of evoking emotion in the context of recall, further processing of the memories may have been colored by emotion. In this regard, use of "unconstrained"—but not explicitly neutral—retrieval instructions may be the superior method.

ERP responses were influenced by the subjective vividness of participants' recollections. In Experiment 1, on trials on which participants reported highly vivid recollections, there was no effect of emotion. In contrast, on trials on which participants reported less vivid recollections, ERPs responses to both positive and negative events differed from those to emotionally unconstrained events. Thus, consideration of vividness and emotion in conjunction with one another resulted in a more canonical "emotion" effect than consideration of emotional valence alone. The effect could be interpreted to suggest that emotion effects are secondary to the vividness of recollection. They arise because typically, emotional stimuli are more vividly recollected, relative to non-emotional stimuli. When the latter are recalled with high vividness, there is no further enhancement of processing associated with emotion, per se. We also note the difference in patterns of neural processing when both emotion and vividness were taken into account, relative to that observed in more typical tests of recognition memory for emotional picture stimuli. Whereas the more typical effect is for emotional memories to elicit more positive-going ERPs, in the present research, ERPs to emotional stimuli were less positive-going. In future research, it will be important to test whether this difference is specific to retrieval-induced emotions. In Experiment 2, emotion and vividness did not interact, yet there were significant differences in processing on trials on which participants reported that they recollected the events with high and low degrees of vividness. As above, the possibility that in Experiment 2, all stimuli were "emotional," may explain the absence of an interaction with emotional valence.

The present research does not afford a direct test of the role of the amygdala in recollection of emotional events or in recollection that is especially vivid—the analyses we employed do not permit localization of the source of the EEG/ERP. Yet, the findings are largely consistent with those from neuroimaging studies that have examined relations between amygdala activity and both emotional valence and vividness. In Ref. [1], amygdala activity during encoding was linearly related to the subjective vividness of subsequent memory. That is, greater amygdala activity as stimuli were encoded was associated with greater subjective ratings of the vividness of the memory. The links were observed across all types of emotional items: positive, negative, and neutral. Thus, the activity was not restricted to items that were especially emotional. Kensinger and colleagues [1] speculated that the details of events that are enhanced by amygdala activity—including item-specific details—may be those that figure especially prominently in participants' evaluations of the vividness of their recollections. Maintaining the vividness of recollection over long delays may be especially dependent on connectivity between the amygdala and hippocampus [49].

One limitation of the current study is that it does not directly inform us on the manner in which emotion may influence the cognitive components of retrieval or how it influences subjective sense of vividness of recollection. Although mechanisms by which emotion influences memory encoding are fairly well established (e.g., [50, 51]), the manner in which emotion influences retrieval—and thus the vividness thereof—is less clear. Previous ERP studies of emotional retrieval have used recognition paradigms exclusively [52–57]. Using recognition tasks to examine the effects of emotion on retrieval presents multiple difficulties. The repetition of the emotional stimulus at retrieval may initiate new emotional responses that overlap with responses to the retrieved memory. One previous method for controlling the emotion of the retrieval cue has been to have participants read a neutral word within an emotional sentence context during encoding and then use the neutral word as a cue during later retrieval [53]. Similarly, the cue word paradigm used in the current research used neutral words to cue the retrieval of emotional memories. However, the cue word procedure probes recall, a more demanding form of retrieval than recognition in that the to-be-retrieved material is not present in the retrieval environment. For this reason, recall involves the recruitment of greater and more widespread neural resources than recognition [58] and is likely to be a more sensitive task for detecting the neural processes involved in event memory retrieval. Few previous studies have examined autobiographical memory using ERP [59–61]. The current research provides novel method for investigating the component processes of retrieval.

In conclusion, the present research revealed differential ERP responses to cue words associated with autobiographical memories that themselves differed in terms of the prevailing emotion and the vividness of recollection. Although the techniques employed cannot inform the particular roles of specific neural structures involved in memory, they are largely consistent with findings that the amygdala plays a central role in processing not only emotional but also highly vivid episodic memories. The research implies that focus on the single dimension of the emotion associated with an event, without conjoint consideration of the vividness of the recollection of it, misses important aspects of neural processing, thus undermining our understanding of memory and its determinants.

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Appendix A. Cue words

airplane	camera	dream	hill	night	soda
baby	candy	drink	house	ocean	sofa
ball	car	field	internet	office	squirrel
band	card	fire	key	paint	star
bank	chair	flower	kitchen	paper	store
bed	child	friend	lamp	parent	sun
bicycle	city	fruit	letter	park	table
bird	class	game	library	party	teacher
bill	computer	gas	lunch	plant	telephone
book	cup	gift	mail	radio	television
box	dinner	grass	map	rain	toothbrush
bread	dirt	gum	milk	shirt	train
bridge	doctor	hair	money	shoe	tree
bug	dog	hand	music	snow	water
cake	door	hat	neighbor	soap	window

Appendix B. Sample narratives for the cue word *Park*

Park (Neutral):

I went to the Dogwood Festival at Piedmont Park, and lied down on the grass and watched the clouds.

Additional keyword for park: Festival

Rate the intensity of your emotional response…

How did you feel when it happened? (2) Little Emotional Response

How do you feel when thinking about the event now? (1) No Emotional Response

Rate the pleasantness of your emotional response to the memory when thinking about it now: Neutral

Park (Negative):

This is the place where my last girlfriend and I officially broke up. I felt very upset because she felt unprepared for the relationship.

Additional keyword for park: Breakup

Rate the intensity of your emotional response…

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How did you feel when it happened? (5) Strong Emotional Response

How do you feel when thinking about the event now? (5) Strong Emotional Response

Rate the pleasantness of your emotional response to the memory when thinking about it now: Very Unpleasant

Park (Positive)

Cate, Yamini, and I went to Olympic park. Even though we were all wearing jeans, we decided to run through the fountains over and over again.

Additional keyword for park: Fountains

Rate the intensity of your emotional response…

How did you feel when it happened? (5) Strong Emotional Response

How do you feel when thinking about the event now? (4) Moderate Emotional Response

Rate the pleasantness of your emotional response to the memory when thinking about it now: Very Pleasant

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