How personal experience modulates the neural circuitry of memories of September 11

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Brown and Kulik [Brown R, Kulik J (1977) *Cognition* 5:73–99] introduced the term "flashbulb memory" to describe the recall of shocking, consequential events such as hearing news of a presidential assassination. They proposed that the vivid detail of such memories results from the action of a unique neural mechanism. In the present study of personal recollections of the terrorist attacks of September 11, 2001 (9/11) in New York City, we combine behavioral and brain imaging techniques, with two goals: (*i*) to explore the neural basis of such memories and (*ii*) to clarify the characteristics of the emotional events that may give rise to them. Three years after the terrorist attacks, participants were asked to retrieve memories of 9/11, as well as memories of personally selected control events from 2001. At the time of the attacks, some participants were in Downtown Manhattan, close to the World Trade Center; others were in Midtown, a few miles away. The Downtown participants exhibited selective activation of the amygdala as they recalled events from 9/11, but not while they recalled control events. This was not the case for the Midtown participants. Moreover, only the Downtown participants reported emotionally enhanced recollective experiences while recalling events from 9/11, as compared with control events. These results suggest that close personal experience may be critical in engaging the neural mechanisms that underlie the emotional modulation of memory and thus in producing the vivid recollections to which the term flashbulb memory is often applied.

amygdala | emotion | flashbulb | fMRI | memory

Laboratory investigations of the influence of emotion on human memory are constrained by ethical limitations that prohibit inducing strong emotions in study subjects. Therefore, to determine the impact of emotion on memory, researchers have often examined memories of shocking public events (1–5). In the first study of this type, Colgrove (2) found that most participants could recall what they were doing and where they were when they learned that President Lincoln had been assassinated, even though considerable time had passed since the actual event. A century later, Brown and Kulik (1) reported similar findings in a study examining memories of the assassinations of President John F. Kennedy and other political figures. On the basis of their results, Brown and Kulik suggested that the surprising and consequential nature of these public events triggers a unique mechanism that conserves what occurred at that instant, producing a picture-like representation commonly called a "flashbulb memory."

Although there is little doubt that these groundbreaking studies captured the subjective qualities of memories for these historic events, the claim that there is a unique mechanism underlying memories for shocking public events has been controversial. Brown and Kulik's initial suggestion (1) relied on the assumption that these vivid and detailed recollections were unusually accurate. However, these original studies were based on an analysis of memories reported several years after the initiating event (1, 2). The memories were not compared with self-reports collected shortly after the shocking events or with memories for nonemotional events. When such comparisons were made by later researchers, it was found that, like normal memories, flashbulb memories are susceptible to forgetting (3–8), perhaps at the same rate as other memories (5). Although some features of the recollective experience associated with flashbulb memories appeared to be distinct, such as their vividness or the degree of confidence in which they are held, for many investigators the similarities in the rate of forgetting imply that it is unnecessary to posit a unique mechanism; "ordinary" mnemonic mechanisms will do.

Given the significant debate concerning the mechanisms that produce flashbulb memories, it is surprising that no one to date has taken advantage of neuroimaging techniques to explore the underlying brain mechanisms. This was one of the goals of the present study.

Although the brain mechanisms underlying memories for shocking public events have yet to be identified, laboratory studies have specified the neural systems related to the influence of emotion on memory. Investigations across species have shown that the neurohormonal changes that occur with emotional arousal selectively engage the amygdala, which in turn modulates the encoding, storage, and retrieval of episodic memory (9–14). The result is memories that are retrieved with an enhanced recollective experience (14, 15), similar to the suggested qualities of flashbulb memories. In light of these similarities, we hypothesized that the amygdala may be important in the encoding and retrieval of memories for emotional public events. Because the role of the amygdala in memory is explicitly tied to the increase in arousal that is induced by the emotional event (16), factors that influence arousal should also influence the nature of these memories. Consistent with this proposal, it has been reported that the constancy of flashbulb memories over time varies depending on individual factors related to the arousal response, such as emotional engagement (7, 8) and personal involvement with the shocking event (4).

Because of practical constraints in measuring brain responses to surprising public events, we could not examine the mechanisms of encoding and memory accuracy in the present study. However, we were able to assess memory retrieval and another important feature of flashbulb memories, the recollective experience. As mentioned earlier, a number of studies have shown that flashbulb memories are distinguished from other memories by their recollective experience, irrespective of their accuracy (3–5). In a laboratory study, the strength of amygdala activation at retrieval was shown to correlate with an enhanced recollective experience for emotional scenes, even when accuracy was not enhanced (14). We propose that the recollective experience of flashbulb memories also varies depend-

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Abbreviations: fMRI, functional MRI; WTC, World Trade Center.

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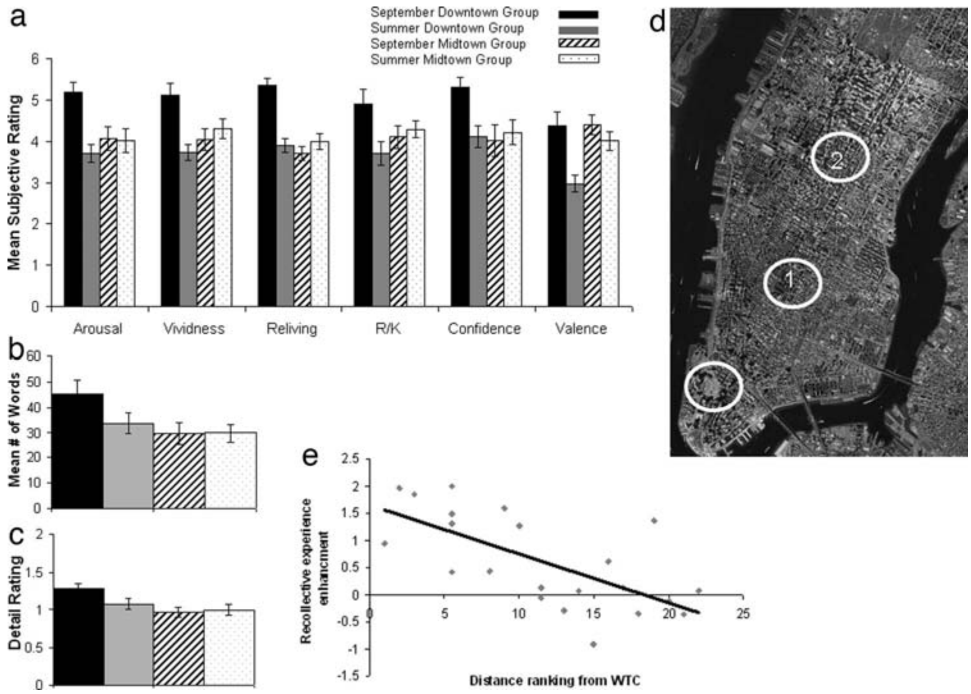

Fig. 1. Recollective experience and proximity to the WTC. (*a*) Subjective ratings of memories, from 1 (low) to 7 (high). For valence, the scale ranges from 1 (positive) to 7 (negative). (*b*) Average number of words used to describe memories. (*c*) Ratings by naïve judges of memory description detail, from 0 (low level of detail) to 2 (high level of detail). (*d*) Aerial image of Manhattan showing the average distance of participants from the WTC (white circle, lower left) on 9/11 for the Downtown group (1) (mean distance = 2.08 mi) and the Midtown group (2) (mean distance = 4.53 mi). (*e*) Correlation scatter plot across all groups for enhancement in recollective experience, defined as the average differential scores on all subjective scales for 9/11 memories vs. summer memories, with participants' distance from the WTC defined by ranking participants from the individual closest to the WTC to the individual farthest from the WTC.

ing on factors linked to arousal, such as the individual's personal experience of the event (4).

Approximately 3 years after the 9/11 terrorist attacks, 24 participants who were in Manhattan on that day were asked to retrieve 60 autobiographical memories related to a word cue (17, 18) presented on a screen while in a functional MRI (fMRI) scanner. The words "summer" or "September" were used to indicate whether the autobiographical memory should be of an event that occurred on 9/11 or during the preceding summer (i.e., June–August 2001). Most previous studies examining the recollective experience of flashbulb memories have compared them with memories of everyday events (5) or with no baseline at all (4). Here, we compare these memories with distinct, meaningful autobiographical memories (such as of a summer vacation). This allowed us to investigate whether the enhanced recollective experience for these memories is associated with the shocking, emotional aspects of the event or is simply a general characteristic of memories for distinct life events.

After the scanning session, participants rated their memories on the basis of six factors proposed to characterize the recollective experience of flashbulb memories: arousal, vividness, reliving, remember/know (R/K), confidence, and valence (see ref. 19 and Fig. 1*a*). They then wrote a description of their memory. Finally, participants completed a survey assessing their personal experience of the terrorist attacks, including their physical location at the time of the attacks, and a similar survey for the events experienced during the summer of 2001.

Results

Behavioral Data. ***Subjective ratings.*** For each participant, we conducted a paired-sample *t* test to compare the average ratings for 9/11 trials with those for summer trials across six scales. Although previous studies have reported enhanced ratings on these scales for 9/11 memories relative to memories for everyday events (5), we found that only 12 participants rated their memories from 9/11 significantly higher on these measures relative to distinct autobiographical memories from the preceding summer (Fig. 1*a*). Participants were thus divided into two groups: (*i*) those who rated their memories from 9/11 significantly higher on the six measures relative to memories from the summer of 2001 ($P < 0.05$, $n = 12$; 9 males and 3 females, mean age = 24.75 years) and (*ii*) those who did not ($P > 0.1$, $n = 10$; 5 males and 5 females, mean age = 25.33 years). One participant with an intermediate P level (0.098) was not assigned to either group. Reaction times did not differ between trial types or groups.

Participants' difference scores (9/11, summer) across the six scales were correlated. For simplicity, in all subsequent analyses we will use the average difference score across the six scales for each participant as an indicator of the relative enhancement of recollective experience for 9/11 memories.

Postscanning survey. To discover which factors were related to the difference in ratings for 9/11 memories between these two groups, we examined their responses on the survey regarding their experiences on 9/11 and during the summer of 2001. The primary factor that differed between the two groups was proximity to the World Trade Center (WTC). Participants who rated their 9/11 memories higher on the measures of recollective experience were significantly closer to the WTC at the time of the attacks [mean distance from the WTC = 2.08 mi (1 mi = 1.6 km), SD = 1.16; referred to as the Downtown group] than those who did not (mean distance = 4.53 mi, SD = 3; referred to as the Midtown group) [t (19) = 2.5, $P < 0.025$] (Fig. 1*d*). The distance of the participants from the WTC correlated with the average enhancement in recollective experience for 9/11 memories relative to summer memories ($r = -0.67$; $P < 0.05$) (Fig. 1*e*). The participants in the Downtown group also reported on the postscanning survey a higher level of negative valence related to 9/11 events relative to summer events than did the

Midtown group [t (19) = 2.32, $P < 0.05$] and showed a similar trend in reported arousal levels [t (19) = 1.93, P = 0.07].

Memory detail. Two objective assessments of the level of detail of the written memories revealed the same pattern of results as the ratings of recollective experience (Fig. 1 *b* and *c*). The average number of words in the written descriptions of the 9/11 memories for the Downtown group was greater than for the Midtown group [t (20) = 2.17, $P < 0.05$] but did not differ for summer memories. Further, the Downtown group used more words to describe 9/11 memories than to describe summer memories [t (11) = 3.57, $P < 0.005$], but this was not the case for the Midtown group.

In addition, two naïve judges rated each written memory for amount of detail on a scale from 0 (low level of detail) to 2 (high level of detail). Ratings of detail for memories of 9/11 were higher for the Downtown group than for the Midtown group [t (20) = 3.21, $P < 0.005$] but did not differ for summer memories. Ratings of detail for 9/11 memories were higher than for summer memories in the Downtown group [t (11) = 3.53, $P < 0.005$] but did not differ for the Midtown group.

Memory content. We examined how proximity to the WTC was related to the participants' experience on 9/11, as indicated by their written memories. A search of the 9/11 memories by a naïve judge revealed that none of the participants in the Midtown group mentioned direct personal threat (e.g., trying to avoid falling debris); however, 41% of the participants in the Downtown group did. In addition, all of the participants in the Downtown group, and 60% of the participants in the Midtown group, mentioned direct sensory experience related to the terrorist attacks (e.g., seeing the buildings collapse). The number of memories in which direct threat and sensory experience were mentioned was greater for the Downtown group than for the Midtown group [threat: t (19) = 2.7, $P < 0.025$; sensory experience: t (19) = 2.4, $P < 0.025$].

fMRI Data. The behavioral data suggest that the recollective experience for memories of 9/11 differs from that for other memorable life events only for participants who were close to the WTC. We would expect these differences to be reflected in the brain activity underlying retrieval of those memories in the two groups.

The amygdala was the *a priori* brain region of interest (ROI) in our study. Percentage signal change values for the peak active voxel within this structure were determined bilaterally by contrasting 9/11 trials with summer trials for all participants. The peak active voxel in the left amygdala (Fig. 2*a*) revealed a two-way (group × condition) interaction [F(1, 20) = 7.04, $P < 0.025$] (Fig. 2*b*). Activation was greater during 9/11 trials than during summer trials for the Downtown group [t (11) = 2.98, $P < 0.025$] but did not differ for the Midtown group. In the Downtown group, 83% of participants showed numerically higher activation in the left amygdala during 9/11 trials than summer trials. In comparison, only 40% of the Midtown participants showed this pattern of activation. During the 9/11 trials, the Downtown group showed higher activation than the Midtown group [t (20) = 1.92, $P < 0.05$, one-tailed]. There was no difference across groups for summer trials. The differential percentage signal change values in the left amygdala correlated with the differential scores for recollective experience (r = 0.44, $P < 0.05$) and with the proximity of the participants to the WTC during the attacks [point-biserial coefficient (r_{pb}) = −0.45, $P < 0.05$]. The statistical analysis on percentage signal change in the peak active voxel in the right amygdala did not yield significant findings.

Whole-brain exploratory analysis [see supporting information (SI) Tables 1 and 2] revealed the right posterior parahippocampal cortex as one of the few regions that was more engaged during the retrieval of summer memories than 9/11 memories in the Downtown group relative to the Midtown group. Previously, enhanced activation in this region was observed during the retrieval of neutral photographs judged to be vividly remembered relative to neutral photographs judged to be only familiar and to all emotional photographs (see ref. 14; also see ref. 10 for similar findings during encoding). In contrast, enhanced response in the amygdala was observed only for emotional photographs judged to be vividly remembered (14).

Given these previous results and the current finding that the recollective experience for 9/11 memories is correlated with proximity to the WTC, we conducted an analysis of covariance (ANCOVA) on the brain imaging data, with distance from the WTC as a covariate. A positive correlation was found in the right posterior parahippocampal cortex (r_{pb} = 0.59, $P < 0.002$; Fig. 2*d*), and a negative correlation was found within the right and left amygdala [left: r_{pb} = −0.49, $P < 0.02$ (Fig. 2*c*); right: r_{pb} = −0.50, $P < 0.02$]. In other words, participants who were closer to the WTC on 9/11 showed decreased activation in the posterior parahippocampal cortex and increased activation in the amygdala during retrieval of 9/11 memories relative to summer memories.

These results confirm the findings derived from the ROI analysis, suggesting a role for the left amygdala in retrieval of vivid memories from 9/11 for participants who were close to the WTC. Contrary to the exploratory analysis, the ROI analysis did not yield significant findings in the right amygdala. This may suggest that the left amygdala is more dominant during autobiographical retrieval (also see ref. 20), consistent with a general left-hemisphere bias during autobiographical memory retrieval (21).

Discussion

In the current study, we have identified a neural system linked to the retrieval of memories for shocking public events. Perhaps not surprisingly, the amygdala, which has been shown in laboratory

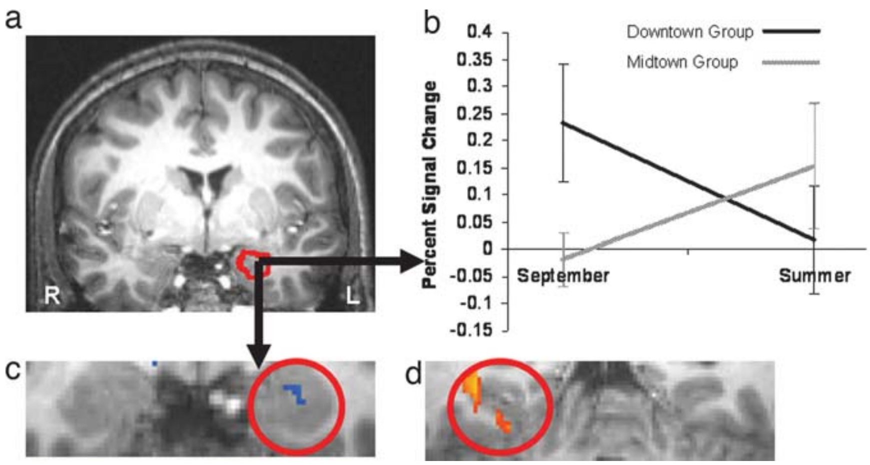

Fig. 2. Blood oxygen level-dependent (BOLD) response and proximity to the WTC. (*a*) Coronal slice of the structurally defined left amygdala (outlined in red) that includes the peak active voxel. (*b*) Mean percentage signal change from the peak active voxel in the left amygdala, revealing a two-way interaction of trial type (9/11 vs. summer) × group (Downtown vs. Midtown). (*c* and *d*) ANCOVA contrasting activation during 9/11 trials vs. summer trials, with participants' distance from the WTC as a covariate, in voxels within the structurally defined amygdala (*c*) and posterior parahippocampal cortex (*d*). Warm colors indicate positive correlation, and cool colors indicate negative correlation ($r_{pb} < 0.02$, uncorrected). Participants who were closer to the WTC showed decreased activation in the posterior parahippocampal cortex and increased activation in the amygdala bilaterally during retrieval of 9/11 memories relative to summer memories.

studies to play an important role in the influence of emotion on memory (10–14), was found to play a role in the retrieval of memories for the 9/11 terrorist attacks in New York City. Less predictable, however, was the significant variability we observed in both the amygdala response and the recollective experience for memories of 9/11 among individuals who were in New York City on that day.

The retrieval of memories for 9/11 was accompanied by an enhancement in recollective experience relative to the retrieval of other memorable life events in only a subset of participants who were, on average, 2 miles from the WTC (around Washington Square) and not in participants who were on average 4.5 miles from the WTC (around the Empire State Building). Although all participants were in Manhattan on 9/11, the recollections of those who were in Downtown Manhattan, close to the WTC, were qualitatively different from the recollections of those who were farther away. The Downtown participants reported seeing, hearing, and smelling what had happened: "I saw with my own eyes: The towers burning in red flames, noises and cries of people." Conversely, participants who were, on average, around Midtown reported experiencing the events secondhand: "I was in the office and heard about the attack. I looked on the Internet"; "I remember watching TV news coverage at Café Tacci and presumably hearing sounds of explosions on TV." Participants who were Downtown also reported real and/or perceived threat: "The explosion caused everyone in the area to automatically duck for cover. I saw some scaffolding that I could go under to avoid the falling debris." It is clear from these recollections that proximity to the WTC changed the nature of the experience of these events, such that those participants who were Downtown on 9/11 had greater direct personal experience of the terrorist attacks.

In accord with the behavioral results, neural circuits shown to be related to an increase in the recollective experience of emotional stimuli learned in a controlled laboratory setting (10, 14) were engaged during retrieval of 9/11 memories in participants who were Downtown. Specifically, both a relative elevation in amygdala activity and decreased activity in the parahippocampal cortex during retrieval of 9/11 events were related to the participants' proximity to the WTC. The posterior parahippocampal cortex has been implicated in the processing (22) and recognition (23) of scene details and may be differentially involved in successful encoding of neutral scenes relative to emotional scenes (10). It has been suggested that when viewing an emotional event, attention is focused on the central arousing aspects of the event at the expense of peripheral details, resulting in impoverished encoding of scene details (24). This finding has been linked to amygdala function (25). It is possible that this impoverished encoding of scene details results in less involvement of the posterior parahippocampal cortex during encoding, and subsequent retrieval, of an arousing event.

Relevance to Flashbulb Memory. To contemplate the importance of these findings to an understanding of flashbulb memories, it is necessary to consider what constitutes a flashbulb memory. Flashbulb memories were initially defined by Brown and Kulik (1) as "memories for the circumstance in which one first learned of a very surprising and consequential event" (page 73 of ref. 1), which contain a subset of six canonical features: place, ongoing activity, informant, own affect, other affect, and aftermath. Such memories were proposed to be exceptionally vivid and detailed, resistant to forgetting, and formed by a special biological mechanism (1). Most of these initial properties of flashbulb memories have been debated since Brown and Kulik first coined the term.

First, studies have shown that flashbulb memories can result from nonsurprising events (26), such as the first moon landing (27), and also from nonconsequential events (28). Second, although Brown and Kulik defined flashbulb memories as memories of first learning about the shocking event, they expand this definition in their discussion to include personal events in which the memory is of the event itself. Indeed, simply asking participants to retrieve vivid, autobiographical memories has been shown to yield memories that contain the canonical features of flashbulb memories (28). Third, it has been suggested that flashbulb memories are not especially resistant to forgetting (3–5). Finally, prior to the current study there has been no evidence for the unique biological mechanism proposed by Brown and Kulik.

The only characteristic of flashbulb memories that has yet to be challenged is the vividness of the memory. A number of studies suggest that flashbulb memories are not especially accurate (3–5) but that they are experienced with great vividness and confidence (3–8). Thus, as previously suggested (28), it may be more precise to define flashbulb memories as extremely vivid autobiographical memories. Although they can be memories of learning about a shocking public event, they do not have to be of such events, and not all memories of learning about shocking public events produce flashbulb memories (30).

How the findings of the present study relate to flashbulb memories is contingent on one's definition of flashbulb memory. If it is defined as the recollection of the circumstance of first learning about a shocking event, then our study does not strictly examine flashbulb memories. Brain imaging techniques require averaging across a number of trials. Because of this, we sampled different episodes from 9/11. An examination of the 9/11 memories in the present study shows that all of the participants' memories included a sufficient number of Brown and Kulik's six canonical features (1) to qualify as flashbulb memories; however, we did not restrict our analysis to the retrieval of these features alone. Rather, we used cue words to sample memories from that day. Cue words may produce a less narrative-based search and may trigger different types of memories (31) that have been less rehearsed. However, if we define flashbulb memories simply as memories for shocking public events, all of the memories from 9/11 are flashbulb memories in that they are all of events related to the terrorist attacks. Finally, if one defines flashbulb memories as uniquely vivid and detailed recollections, only a subset of the participants, the Downtown group, had flashbulb memories of 9/11.

It is clear that there is no general consensus as to the precise properties that distinguish flashbulb memories; however, a sense of vividness and confidence appears to be the most salient and consistent characteristic. Given this, the present study contributes to the literature of flashbulb memories by identifying the neurological substrates involved in recollecting vivid, confident memories of an emotional, public event. With this in mind, we discuss the implication of our data for the underlying mechanisms of flashbulb memories and suggest a role for personal experience.

Insights into the Mechanisms of Flashbulb Memories. There has been considerable debate as to whether unique mechanisms are involved in the formation of flashbulb memories or whether ordinary memory processes are sufficient to account for the characteristics of memories for shocking public events. Our investigation of the neural circuitry of flashbulb memories indicates that the underlying mechanisms may be more nuanced than this dichotomy suggests.

For individuals who were close to the WTC, the retrieval of 9/11 memories engaged neural systems that are uniquely tied to the influence of emotion on memory. On the one hand, the engagement of these emotional memory circuits is consistent with the unique limbic mechanism that Brown and Kulik (1) suggested. On the other hand, these are the same neural mechanisms engaged during the retrieval of emotional stimuli in the laboratory (14). The consistency in the pattern of neural response during the retrieval of emotional scenes presented in the laboratory and flashbulb memories suggests that even though different mechanisms may be involved in flashbulb memories, these mechanisms are not unique to the surprising and consequential nature of the initiating events.

For participants who were farther away from the WTC on 9/11, we found that memories for 9/11 did not differ from other distinct autobiographical memories in either their recollective experience or the underlying neural circuitry. Given the frequency with which flashbulb memories are reported in reaction to shocking public events among participants who are far away from the initiating event, it is somewhat surprising that the subset of participants who were around Midtown Manhattan would fail to show the enhanced recollective experience characteristic of flashbulb memories in their recollections of 9/11.

There are two possible reasons for this discrepancy. First, we did not restrict our analysis to memories for the circumstances of first learning about the terrorist attacks. It may be that these memories are especially vivid for most participants, but that the enhanced recollective experience of other memories from 9/11 is contingent on direct personal experience. Second, it may be that for the Midtown participants the overall number of vivid recollections from 9/11 was smaller compared with the key events of a whole summer. One of the challenges in studies of flashbulb memories has been to define an appropriate baseline task. The initial reports on flashbulb memories failed to include any comparative baseline (1). Later studies examined the consistency of such memories over time (3–5) or compared them with memories for everyday events (5). In contrast, the baseline events in our study were distinct and meaningful life events. Although memories for 9/11 may result in an enhanced recollective experience relative to memories of script-like life events, such as a study session, this enhancement might reflect mechanisms that are shared with the types of distinct autobiographical memories assessed in our study. If memories for 9/11 are not differentiated from other distinct autobiographical events in participants who were only 5 mi away from the WTC, this raises the question of how unique these memories, and their underlying mechanisms, are for most people.

Personal Experience and Flashbulb Memory. We found evidence for the importance of the amygdala in the retrieval of 9/11 events but only among individuals who personally experienced these events. The amygdala's influence on episodic memory is explicitly tied to physiological arousal (16). Although simply hearing about shocking public events may result in arousal, the strength of this response likely varies depending on the individual's personal experience with the events. The effect of personal experience on arousal is proposed to underlie the observed correlation between proximity to the WTC and the amygdala response.

The relationship between arousal and personal experience may also explain some of the discrepancies in reports on the accuracy of flashbulb memories. In contrast to studies suggesting that flashbulb memories are not particularly accurate (3, 5), it has been shown that when there is a greater emotional engagement (7, 8) and personal involvement (4) with the shocking public event there is also greater accuracy. In a classic study (4), it was reported that memories for the 1989 San Francisco earthquake were more consistent over 18 months in participants who were in San Francisco at the time than for those who were in Atlanta, GA, suggesting that personal experience may play an important role in the quality of memories for emotional public events.

Neisser *et al.* (4) proposed that direct experience with an event promotes narrative rehearsal, which subsequently enhances memory accuracy. However, a later study reported that for longer retention intervals ($\approx$3 years), emotional involvement rather than rehearsal predicts the enhancement in accuracy of flashbulb memories (8). Controlled laboratory studies have also tied the augmentation of memory to arousal in the absence of narrative rehearsal (10). Although it is possible that the Downtown group in the present study retold their experiences of 9/11 more frequently than the Midtown group, we find it less plausible that retelling alone underlies the enhancement in recollective experience of the terrorist attacks 3 years later. We propose that the effect may be due to the amygdala's modulation of episodic memory with arousal, as mediated by personal experience.

Caveats. Our finding that 9/11 memories do not differ from memories for other distinct autobiographical events unless there is personal experience may be at odds with the intuitive sense that individuals who were outside of New York City on 9/11 may have when reflecting on their memory. One of the ways in which memories for 9/11 may differ from those for other distinct autobiographical events is that the terrorist attacks likely yielded a number of distinct autobiographical memories in a relatively short period of time. The number of discrete details recalled from any single event may influence the overall judgment of recollective experience for the entire event (32). Although our assessment of the recollective experience for each individual memory retrieved did not yield any difference between memories from 9/11 and other distinct autobiographical events in the Midtown participants, it is possible that the overall judgment of recollection for memory of 9/11 would be greater than for any of the other autobiographical events simply because of the sheer number of distinct memories from that single day.

Conclusion

In the period since Brown and Kulik (1) proposed that a unique limbic mechanism underlies flashbulb memories, no neural evidence has been sought to confirm or contradict this claim. In the present work, we show evidence for this mechanism, specifically enhanced activation in the amygdala, but only for the subset of participants who were physically close to the WTC on 9/11. For participants as little as 5 mi away, no such activation was observed. These results imply that, for the vast majority of individuals, memories from 9/11 may not differ from other distinct autobiographical memories in either their recollective experience or their engagement of limbic mechanisms.

Evidence is mounting that memories for shocking public events have very few of the flashbulb qualities initially suggested by researchers (3–5, 28). The current findings, like earlier reports (4, 28), are inconsistent with the common belief that traumatic public events will result in a unique mnemonic experience for most people. As has been suggested (28), flashbulb memories may not differ fundamentally from other distinct autobiographical memories. However, our findings also indicate that personal experience plays an important role in producing memories with the qualities initially attributed to flashbulb memories, including the engagement of limbic mechanisms (1). The experience of immediate emotional involvement brought about by directly observing, or participating in, highly arousing events gives rise to exceptionally vivid memories. The present findings suggest that personal experience with the shocking public event may yield a different type of memory, perhaps one more consistent with the range of qualities proposed by Brown and Kulik in their seminal paper (1).

Methods

Participants. Twenty-nine participants (age 20–33 years) were recruited for this study through posted advertisements. Three were eliminated because of head movement (>2 mm on any dimension). Two participants who did not have at least 10 trials of each condition for which reaction times were at least 5 s were also excluded (33, 34). The remaining 24 participants (16 males and 8 females) were included in the analysis. An ANOVA (trial type $\times$ gender) conducted to examine the influence of gender on amygdala activation did not reveal a significant interaction [$F(1, 20) = 0.012, P > 0.5$]. All subjects gave informed consent and were compensated for their participation.

Stimuli. Sixty cue words were selected from a list used previously (35) and from our own set of words (see *SI Appendix*). The order and condition in which the cue words were presented were random.

Procedure. A structural scan was performed first, followed by three functional scans (10 min 40 s each), each consisting of 20 trials of

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32 s. On each trial, the cue word and the word indicating the condition of the trial (either "September" or "summer") appeared until the participant pressed a button indicating that a memory was fully recovered. If the participant did not press the button, the words would disappear after 20 s and that trial would be excluded from further analysis. Fixation cross was presented for the reminder of the trial.

After the scanning session, participants were presented with the same trials again on a computer screen and rated their memories on six scales adapted from a previous study (19). Because of a computer error, rating data for one participant were lost, and he was eliminated from further analysis. Participants were then asked to key-in a self-description of their memories. Finally, participants completed a survey assessing their personal experience of the terrorist attacks and completed a similar survey for the events experienced during the summer of 2001.

Behavioral Data Analysis. Behavioral data were analyzed as described in *Results*.

MRI Scanning and Data Analysis. The study was conducted at the New York University Center for Brain Imaging, using a 3T Allegra scanner (Siemens, Iselin, NJ). Anatomical images were acquired by using MPRAGE scans. Functional scans used a gradient echo sequence, 35 slices parallel to the anterior commissure/posterior commissure (AC–PC) plane, repetition time = 2 s, echo time = 30 ms, flip angle = 90°, field of view = 192 mm, in-plane resolution = 3×3 mm.

Imaging data were analyzed with Brain Voyager software (QX; Brain Innovation, Maastrich, The Netherlands). Data were temporally and spatially smoothed (4-mm FWHM), motion-corrected, and transformed into Talairach space for group analysis. Electrophysiological studies (33, 34) suggest that the average time taken to retrieve autobiographical memories by using word cues is 5 s (range: 3–9 s). Here, participants were instructed to press a button when a memory was fully elaborated (not simply "retrieved"); for this reason, only trials with retrieval times >5 s were included in the analysis. For each participant, a time series was created indicating the temporal position of the last 4 s of (*i*) 9/11 trials and (*ii*) summer trials, at which time memories were presumed to be fully recovered (33, 34). Data for individual trial types were convolved with the canonical hemodynamic response by using a general linear model (GLM).

The amygdala (*a priori* ROI) was structurally defined according to landmarks described previously (36). Active voxels within this region bilaterally were identified by contrasting 9/11 trials with summer trials, using a GLM on the data of all participants regardless of group membership. Time course of activation was extracted from the peak active voxel for the different trial types for each participant. Percentage signal changes were calculated for each trial type and participant 8 s after stimuli onset. Two-way ANOVA (group $\times$ condition) and *t* tests were conducted on these values. A correlation analysis was conducted between the differential percentage signal change (9/11 trials relative to summer trials) and (*i*) the differential subjective ratings and (*ii*) the three measures from our survey that showed significant differences between the two groups (i.e., differential arousal and valence ratings, and distance from the WTC). For correlations with distance, a point-biserial analysis was used. Although all participants were in New York City on 9/11, the variation in distance from the WTC was uneven among those closer and farther away, with those closer being bunched together; therefore, participants were assigned to two groups based on their reported location during the attacks. These values, indicating distance from the WTC, were also used as a covariate in an ANCOVA contrasting activation during 9/11 trials relative to summer trials in all voxels within the structurally defined amygdala and posterior parahippocampal cortex.

To identify other voxels in the brain, outside of the *a priori* ROI, that showed stronger BOLD responses during one trial type than the other, we conducted a whole-brain exploratory analysis on group data by using a random-effects GLM (at $P < 0.002$, uncorrected; >5 contiguous voxels).

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