

Memories for emotional autobiographical events following unilateral damage to medial temporal lobe

Tony W. Buchanan,¹ Daniel Tranel¹ and Ralph Adolphs^{1,2}

¹Division of Cognitive Neuroscience, Department of Neurology, University of Iowa, Iowa City, IA and

²Division of Humanities and Social Sciences, California Institute of Technology, CA, USA

Correspondence to: Tony W. Buchanan, Department of Neurology, University of Iowa, 200 Hawkins Drive, Iowa City, IA 52242, USA

E-mail: tony-buchanan@uiowa.edu

Abnormalities of both memory and emotion have been reported in patients with unilateral damage to the anteromedial temporal lobe, probably reflecting the functions of the amygdala and hippocampus in these processes. Emotion and memory are also known to interact: emotional experiences often leave remarkably durable autobiographical memories. To explore this interaction, and to extend prior studies to the domain of autobiographical memory, we investigated the recollection of real-life emotional events in patients with unilateral damage to the anteromedial temporal lobe. Twenty-three patients who had undergone unilateral temporal lobectomy for the treatment of epilepsy (12 left, 11 right) and 20 healthy comparison participants completed an emotional autobiographical memory test. Participants were asked to recollect their five most emotional memories from any time in their lives and then they completed a word-cued autobiographical memory task. Participants dated each memory and gave ratings on scales of pleasantness, intensity, significance, novelty, vividness and frequency of rehearsal. Left temporal lobectomy (LTL) and healthy comparison groups generated similar numbers of pleasant and unpleasant memories, whereas the right temporal lobectomy (RTL) group produced significantly fewer memories of unpleasant events ($P < 0.01$). When memories were further categorized according to pleasantness and intensity, the RTL group produced significantly fewer unpleasant/high intensity memories than the other groups ($P < 0.01$). All groups reported more memories from between the ages of 10 and 30 (the so-called autobiographical memory ‘bump’). The results demonstrate a positive bias in the recollection of autobiographical memory following right-sided anteromedial temporal damage. This finding is consistent with the notion that the right, but not the left, anteromedial temporal lobe is involved in the retrieval of negatively valenced, high-intensity memories.

Keywords: hippocampus; amygdala; autobiographical memory; emotion; temporal lobectomy

Abbreviations: LTL = left temporal lobectomy; NC = normal comparison; RTL = right temporal lobectomy

Received March 25, 2005. Revised August 2, 2005. Accepted October 6, 2005. Advance Access publication November 16, 2005

Introduction

The studies of patients with temporal lobe resections have provided a wealth of knowledge about the neural correlates of emotion (Anderson *et al.*, 2000; Adolphs *et al.*, 2001; Funayama *et al.*, 2001; Buchanan *et al.*, 2004) and memory (Scoville and Milner, 1957; Milner, 1966, 1971; Barr *et al.*, 1990; Kopelman *et al.*, 1999; Viskontas *et al.*, 2000; Lah *et al.*, 2004). Differential, lateralized roles of the left and right medial temporal lobes have been reported for both emotion (Silberman and Weingartner, 1986) and memory (Milner, 1971). Research on emotion has demonstrated that right

temporal lobectomy (RTL) patients tend to be impaired at recognizing facial expressions associated with withdrawal states (Anderson *et al.*, 2000), especially fear (Adolphs *et al.*, 2001). Research on declarative memory following temporal lobectomy has shown impairments in both the anterograde (Milner, 1966) and retrograde (Barr *et al.*, 1990) epochs, as well as a lateralized, material-related impairment for verbal information in left-sided cases versus impairment for non-verbal information in right-sided cases (Milner, 1971). The role of the medial temporal lobe in emotion and memory

processing have been studied independently for a number of years. More recently, investigators have begun to examine the neural correlates of the interactions between these two domains of cognition (McGaugh, 2003).

The differential roles of medial temporal lobe structures in the learning of and memory for emotional situations have been studied extensively (Hamann *et al.*, 1997*a, b*; Cahill, 2000; Buchanan and Adolphs, 2004). Although the hippocampus and surrounding cortex are necessary for the encoding of new memories, the amygdala plays a modulatory role in memory, enhancing memory consolidation for emotionally arousing situations (Gold *et al.*, 1975; McGaugh, 2003). In research with amnesic patients who have bilateral hippocampal damage sparing the amygdala, Hamann *et al.* (1997*a, b*) showed that although these patients have reduced global memory performance, they still show the normal enhanced memory for emotional relative to neutral material. This is in stark contrast to studies in patients who have bilateral amygdala damage sparing the hippocampus, who show relatively normal global memory, but a selective impairment in the enhancement of memory by emotion (Cahill *et al.*, 1995; Adolphs *et al.*, 1997). This pattern has been replicated and extended in patients with unilateral temporal lobe damage that included the amygdala: whereas patients with right amygdala damage showed the normal emotional enhancement of verbal memory, patients with left amygdala damage did not show such enhancement (LaBar and Phelps, 1998; Buchanan *et al.*, 2001). These results suggest that the amygdala may enhance intrahemispheric material-specific memory processing under conditions of emotional arousal (Richardson *et al.*, 2004).

Although studies in both animals and humans provide strong support for the idea that the amygdala modulates declarative memory for emotional events, and also provide considerable detail regarding possible material-specific roles and mechanisms underlying this effect, several key questions remain largely unexplored. First and foremost among these is the extension to real-life memories. One large but often neglected gap between studies of emotional memory in animals and in humans is that the animals, presumably, treat experimental encoding conditions like the real thing, whereas humans are typically aware that the memory tasks are artificial and are occurring in the context of an experiment. It would thus be important to explore in more detail the role of the amygdala in autobiographical emotional memory. A second open question concerns the amygdala's role in modulating the encoding, consolidation and retrieval of emotional memories. In animals, there is good evidence for a role in encoding and consolidation, as there is from functional imaging studies in humans. But the amygdala's possible role in modulating retrieval has not been extensively investigated in humans, and human lesion studies have typically been unable to address this question since encoding and retrieval mechanisms can be difficult to tease apart. A third open question concerns the relative roles of the left and the right amygdala in emotional memory, an issue that has been almost entirely unexplored in animal studies, and for which there are

some data in humans, but again largely from laboratory encoding tasks rather than autobiographical memory. The present study thus aimed towards an exploration of these questions, by focusing on an assessment of autobiographical memory for emotional events in participants who had unilateral left or right damage to the amygdala.

Autobiographical memories are often imbued with emotional significance, leaving long-lasting memory traces (Berntsen and Rubin, 2002; Conway, 2003). Patients with amnesia due to bilateral damage to the medial temporal lobe show an impairment in autobiographical memory that tends to be temporally graded from the time of onset of their brain damage (Beatty *et al.*, 1987). In fact, the patients may show entirely intact autobiographical memory for very remote events in their past (Zola-Morgan *et al.*, 1983; Bayley *et al.*, 2003; but see Nadel and Moscovitch, 1997 for a different view). Studies of autobiographical memory in patients with unilateral damage to the medial temporal lobe suggest a similar, although more variable, pattern to that observed following bilateral damage (Barr, 1997; Kopelman *et al.*, 1999; Viskontas *et al.*, 2000; Lah *et al.*, 2004). Although all of these studies show somewhat reduced autobiographical memory in such patients, the effects of laterality of lesion, memory relative to time of onset of the lesion, the time scale of the retention interval and other patient history variables have often been uncontrolled or unexplored. Recently, we have found that patients with bilateral hippocampal, but not amygdala, damage showed a normal pattern of autobiographical memory for emotional events, whereas patients with bilateral medial temporal lobe damage including the amygdala showed a pronounced positive bias in their autobiographical recollections (Buchanan *et al.*, 2005), indicating that the amygdala plays a role in the recollection of autobiographical memories that are strongly emotional. Whether similar effects might be found following unilateral damage to the medial temporal lobe including the amygdala is unknown, and the topic of the present study.

Another issue in autobiographical memory research is the temporal distribution of recollected memories. Previous research on autobiographical memory in normal individuals has identified three components to the distribution of autobiographical memories (Rubin and Schulkind, 1997; Berntsen and Rubin, 2002): (i) childhood amnesia (sharply reduced number of memories reported from the earliest years of life), (ii) a recency effect manifested as a monotonically decreasing retention function that initially drops quickly and then is equivalent for memories from 10 to 20 years ago in older participants, and (iii) the *autobiographical memory bump*, describing the phenomenon of disproportionately superior recollection of events that occurred between the ages of 10 and 30, compared with other epochs in our lives (Rubin and Schulkind, 1997; Berntsen and Rubin, 2002). The 'bump' has been documented specifically when people are asked to remember their 'most important' memories, 'happiest' memories, and in word-cued memory paradigms (Rubin and Schulkind, 1997; Berntsen and Rubin, 2002). These reliable

patterns in the recollection of emotional, real-life events provide a solid benchmark for investigating emotional autobiographical memory in brain-damaged participants.

Although, patients with unilateral damage to the anteromedial temporal lobe may be able to produce detailed recollections of the remote past, the question remains as to the emotional nature and temporal distribution of these memories, and the possible differences between patients with damage to the left versus the right hemisphere. If the right anteromedial temporal lobe plays a disproportionate role in the processing of negative emotional material, as suggested by studies of facial affect recognition (Anderson *et al.*, 2000; Adolphs *et al.*, 2001), then one would expect that damage on the right, but not the left, would result in abnormalities in affective recollections. By contrast, if the right and left anteromedial temporal lobes play similar, or complementary roles in the recollection of the emotional past, then damage to either the left or right anteromedial temporal lobe should produce similar patterns of recollection.

To address these questions, we audiotaped the verbal recollections of 23 subjects with unilateral, focal medial temporal lobe damage and measured the quantity, quality and temporal distribution of their emotional autobiographical memories. Twelve of these patients had damage to the left anteromedial temporal lobe and 11 had damage to the right anteromedial temporal lobe as a consequence of temporal lobectomy.

It should be noted that this investigation is exploratory, owing to the nascent status of this area of research. Thus, we purposely did not formulate specific hypotheses or predictions of expected results, because this would have been contrived: there is simply too little evidence available so far on which to base predictions. Accordingly, our study attempted to address the role of the anteromedial temporal lobe in the recollection of emotional autobiographical memories, to shed light on an area where little is known.

Methods

Participants

Twenty-three temporal lobectomy patients (12 left and 11 right) with damage to the medial temporal lobe including the hippocampus, amygdala and surrounding cortices participated in the study (*see* Table 1 for patient demographics and neuroanatomy). (Additional data concerning seizure and medication status at the time of testing is reported in the Results) Comparison participants were 20 healthy participants (NC group) matched to brain damaged patients on age and gender distribution (*see* Table 1). Age ranges for each group were comparable: left lobectomy group, 30–59 years; right lobectomy group, 24–57 years; comparison group, 31–62 years. All brain-damaged participants were drawn from the Patient Registry of the Division of Cognitive Neuroscience at the University of Iowa. We excluded any participants who had a history of psychiatric illness, and anyone currently taking benzodiazepines, beta-blockers or sedatives, as these could influence memory performance.

Magnetic resonance images were obtained from all brain-damaged patients in a 1.5 T General Electric 4096 Plus scanner. The scanning protocol used in this study is identical to that used

Table 1 Demographic and neuroanatomical characteristics of participants

	Sex	Education	Age at test	Handedness	Age at first seizure	Years post-surgery	Left temporal volume	Left HC volume	Left Amyg volume	Right temporal volume	Right HC volume	Right Amyg volume	
LTL	N = 12	7 F/5 M	13.4 ± 2.5	41.8 ± 9	8R/1M/3L	8.1 ± 7.0	5.4 ± 3.0	46 637* ± 14743	1244* ± 747	717* ± 521	85 001 ± 6647	3878 ± 667	1653 ± 321
RTL	N = 11	5 F/6 M	14.4 ± 2.0	37.6 ± 11	8R/1M/2L	12.6 ± 9.2	8.1 ± 8.3	85 514 ± 7464	3739 ± 491	1884 ± 504	48 669* ± 12 178	1664* ± 851	1061* ± 419
NC	N = 20	10 F/10 M	15.0 ± 2.9	41.8 ± 10	–	–	–	–	–	–	–	–	–

Handedness data: R = right handed, M = mixed handed, L = left handed, as assessed by the Oldfield-Geschwind Questionnaire. Left and Right Temporal volume = temporal lobe volume in mm³; HC volume = hippocampal volume in mm³; Amyg volume = amygdala volume in mm³. Table entries show mean ± standard deviation. *Group difference at $P < 0.0001$, assessed with independent samples t-tests.

by Allen *et al.* (2002). All brains were reconstructed in three dimensions in Brainvox (Frank *et al.*, 1997), an interactive family of programs designed to reconstruct, segment and measure brains from MR acquired images.

The volumes of the temporal lobe, amygdala and hippocampus were traced in both hemispheres of each patient. Whole brain volumes were also determined. All regions were traced by hand on contiguous coronal slices of the brain. Boundaries of the temporal lobe for this study included the temporal pole to the last slice on which the posterior hippocampus was visible (no participant showed damage beyond this slice posteriorly). The superior boundary of the temporal lobe was the sylvian fissure, and the mesial boundary was the parahippocampal fissure (Allen *et al.*, 2002). Criteria for the boundaries of both the amygdala and hippocampus were derived from the atlas of Duvernoy (1988). Using a method similar to that of Convit *et al.* (1999); see also Szabo *et al.* (2001), pointsets tracing the boundaries of the amygdala and hippocampus were first made in parasagittal and axial planes; these pointsets were then projected to the coronal slices to guide the tracing of the region of interests. Total volumes of left and right temporal lobe, hippocampus and amygdala are presented in Table 1. As expected given the classification of the patients, the left temporal lobectomy (LTL) group had significantly smaller left temporal lobe, amygdala and hippocampal volumes than the RTL group, whereas the RTL group had significantly smaller right temporal lobe, amygdala and hippocampal volumes than the LTL group.

All patients were individually administered a neuropsychological battery that included measures of intellectual functioning, anterograde verbal and non-verbal memory, retrograde memory, visual perception, speech and language, executive functioning and mood (~3 h in length; see Tranel, 2005a). Key indices from the neuropsychology battery are presented in Table 2.

All participants gave informed consent to participate in these studies, according to federal and institutional guidelines. The research was approved by the Human Subjects Committee of the University of Iowa.

Procedure

Top 5 emotional memory interview

Participants were first asked to narrate their ‘Top 5 Most Emotional Memories’ from any time period in their life. For each recollection, the participant was asked to provide the month and year of the event to the best of their ability. Finally participants were asked to rate each memory on the following 7-point scales: pleasantness (*equal to my most unpleasant memory to equal to my most pleasant memory*), intensity (*not intense at all to equal to my most intense memory*), significance (*made no difference in my life to changed my life as much as any event*), novelty (*totally routine to equal to my most unusual event*), vividness (*no image to as clear an image as the original*) and frequency of rehearsal (*never to as often as any event in my life*). These instructions and rating scales were adapted from (Rubin and Schulkind, 1997).

Word-cued memory interview

In a second task, memories were elicited using a modified Crovitz–Schiffman paradigm (Crovitz and Schiffman, 1974). Thirty nouns were selected from the Affective Norms for English Words Database (ANEW; Bradley and Lang, 1999). We selected an equal

Table 2 Neuropsychological data

	BDI	WAIS-III		WMS-R		AVLT		VRT		CFT	Famous faces	Landmarks
		VIQ	PIQ	GMI	DRI	Trial5	DR	Correct	Errors			
LTL	10.4 ± 6.7	91 ± 11	100 ± 13	87 ± 13	88 ^{##} ± 11	10.8 ^{##} ± 2.2	8.0 ^{##} ± 3.5	7.5 ± 2	3.7 ± 3	17.8 ± 7	70.3 [*] ± 19.3	34.6 [*] ± 24.0
RTL	8.9 ± 6.6	101 ± 22	104 ± 16	98 ± 17	102 ± 21	12.7 ± 1.8	10.6 ± 2.5	7.0 ± 2	4.4 ± 4	17.1 ± 5	82.3 ± 8.9	55.0 ± 22.1

BDI = Beck Depression Inventory; WAIS-III = Wechsler Adult Intelligence Scale-III (VIQ = verbal IQ; PIQ = performance IQ; FSIQ = full scale IQ); WMS-R = Wechsler Memory Scale-revised (GMI = General Memory Index; DRI = Delayed Recall Index); AVLT = Auditory-Verbal Learning Test (Trial 5 raw score; DR, Delayed Recall Raw score); VRT = Visual Retention Test (number correct; number of errors); CFT = Complex Figure Test (delayed recall raw score); famous faces = % correct recognition out of 155 famous faces (age-matched comparison performance = 85% ± 1.1; Tranel, 2005b); Landmarks = % correct recognition out of 65 famous landmarks (age matched comparison performance = 62% ± 1.8; Tranel *et al.*, 2005). Summary scores are means and standard deviations. *Group difference at P < 0.1, assessed with independent samples t-tests. ##Difference between groups at P < 0.05.

number of words (10 each) from the ANEW categories of negative (e.g. funeral, cancer), positive (e.g. birthday, kiss) and neutral (e.g. museum, snow), although these categories were not used to classify the valence of participants' memories in the current study (see below). The words were read aloud to the participants one at a time and the participants were asked to produce one memory in response to each word. Participants were instructed to provide the date when the event occurred, and to provide ratings on the same scales as before. For both phases of testing, when a participant failed to produce a memory that was specific to place and time, she/he was prompted by the experimenter to produce a more specific memory.

Testing sessions were conducted over one or two sessions, depending on the cognitive stamina of the participant. The collection of all of the information for both phases of testing typically required from 2 to 6 h. The length of the testing session and number of sessions required did not differ systematically between the LTL and RTL groups. All responses were audiotaped and transcribed for later analysis.

We did not assess the veracity of recollections from the patients on the emotional autobiographical memory interview. Several other studies involving these patients have shown that the patients are, as a rule, very unlikely to generate confabulations in these types of memory tasks (Jones *et al.*, 1998, 2000; Tranel *et al.*, 2000, Tranel and Jones, 2005). In fact, there has been rigorous assessment of the veracity of autobiographical memories in previous work (see especially Tranel and Jones, 2005), and confabulation has never emerged as a confounding factor; the patients tend to opt for 'don't know' responses when they are unable to come up with responses to specific memory questions. For these reasons, we were confident that confabulation was of no significant consequence in the current investigation.

Importantly, for both phases of testing, we did not attempt to constrain the time scale of the retention interval (in contrast to other work with memory impaired participants, which has typically constrained time scale to recent and/or remote events; e.g. Zola-Morgan *et al.*, 1983; Bayley *et al.*, 2003, 2005). Rather, we focused on recollections of emotional events from throughout the lifespan. Although this approach makes it more challenging to draw direct comparisons with previous work, our assessment of emotional recollection is a separate question from the assessment of remote versus recent memory that has been the focus of much of the previous research on autobiographical memory.

Scoring

Responses were initially scored as a 'memory' if the response contained a specific narrative that was unique for time and place. For example, an acceptable recollection (e.g. a description of events on a participant's wedding day) including at least time of the year and the year when the event occurred was counted as a memory and included in all subsequent analyses. Unacceptable responses (e.g. in response to the cue word 'museum': 'I don't know when it was, there was an art museum.') were not included in the analyses. This is similar to the binary scoring system utilized by Zola-Morgan *et al.* (1983).

Because we were interested in the emotional characteristics of the participants' recollections, we used each participant's pleasantness ratings to sort their memories into pleasant, neutral and unpleasant categories. This categorization was employed in both the Top 5 Memories and the word-cued memory phases. We chose not to categorize word-cued memories by the *a priori* valence of the word cue because many of the words prompted memories

that were discrepant from their *a priori* valence category (e.g. the ostensibly 'neutral' cue word 'snow' may prompt the recollection of an unpleasant memory by the participant (Buchanan *et al.*, 2005). Memories with a pleasantness rating of 1 or 2 were classified as 'unpleasant', ratings of 3, 4 or 5 were classified as 'neutral' and ratings of 6 or 7 were classified as 'pleasant'. We examined the number of memories in each category separately for the Top 5 Memories and the word-cued memories. Participants' ratings of each memory on the intensity, significance, novelty, vividness and frequency of rehearsal scales were averaged across valence categories for analysis.

Similarly, for analysis of the role of intensity, we classified memories with an intensity rating of 1 or 2 as 'low intensity', ratings of 3, 4 or 5 were classified as 'middle intensity', and ratings of 6 or 7 were classified as 'high intensity'.

It is possible that the recollections labelled as 'pleasant' or 'unpleasant' by the temporal lobectomy patients may be different from the pleasant or unpleasant memories that comparison participants would produce. To assess this possibility, two independent raters blind to the participants' group membership read each transcript of memories of the temporal lobectomy patients. They rated each memory on the same 7 point scale of pleasantness and intensity as used by the patients. Agreement among the patients and the two raters was satisfactorily high for pleasantness (Cronbach's alpha = 0.91) and intensity (Cronbach's alpha = 0.82). This outcome provides validation for the procedure we used to operationalize 'pleasantness' and 'intensity'; that is, when a patient rated a memory as, for example, highly unpleasant and very intense, there was a high likelihood that independent observers would rate the memory exactly the same way, and so on for other degrees of pleasantness and intensity.

Temporal distribution of memories

We considered three dates in relation to memories: (i) To determine the age of the memory itself, the number of months between its reported date of occurrence and the date of testing was calculated. (ii) To determine the age of the subject at the time of the reported event, the number of months between the participant's date of birth and the reported date of the event's occurrence was calculated. (iii) To determine the time of the reported event in relation to the date of brain surgery, the number of months between the reported date of the event's occurrence and the date of brain surgery was calculated. Very often, participants were unable to recall the exact day or month when an event occurred, but were able to recall the season of the year when the event occurred. When a season of the year was given together with the year of an event, this was entered as the first month of the year in which that season begins (e.g. spring = March; summer = June; autumn = September; winter = December). For instance, if the testing took place in October 2000, and a participant reported an event that occurred in the autumn of 1990, that memory would be classified as being 10 years and 1 month (or 121 months) old. For classification of the age of the subject when the memory occurred, the memories were grouped into the decade in which the memory occurred (e.g. a memory from between the ages of 11–20 was placed in the second decade group and so on).

As noted earlier, studies of the distribution of autobiographical memories throughout the lifespan have shown a pattern that includes a 'bump' in recollections between the ages of 10–30, as well as a recency component described by a monotonically decreasing power function, which is very good at predicting the most recent 10–20 years, especially in word-cued memory testing

(Rubin and Schulkind, 1997). We examined the number of memories from each decade (0–10, 11–20, 21–30, 31–40, >40) produced in the Top 5 phase of testing. The ‘bump’ component of word-cued memory testing is contaminated in younger participants like those tested in the current experiment because it overlaps the retention function for the past 10 years (Rubin and Schulkind, 1997; Buchanan *et al.*, 2005), so we do not report the distribution of word-cued memories in this investigation because we are primarily interested in the ‘bump’ phenomenon. Inspection of the distribution of word-cued memories in our participants, in fact, shows no bump in recollection for the 10–30 age range, but greater recollection of more recent memories, as described in previous research on the distribution of word-cued memories in younger participants (Rubin and Schulkind, 1997). Note that ‘important’ or Top 5 memory distributions do not show this retention function (Rubin and Schulkind, 1997), so we examined the distribution of memories reported in the Top 5 memory phase of testing.

For analysis of the Top 5 memory distribution, one participant from each group was unable to produce and/or date 5 memories in this phase of testing; these participants were excluded from this analysis. The number of participants included within each group is indicated in the legend of Fig. 4.

Results

Analyses of pleasant and unpleasant memories

The analyses in this section used a 2 Sex \times 3 Group (LTL, RTL and NC) \times 3 Valence (Pleasant, Unpleasant and Neutral) analysis of variance (ANOVA). Planned contrasts examining group differences were conducted using the Games-Howell multiple comparison procedure for unequal sample sizes (Games and Howell, 1976). The eta-squared (η^2) measure of effect size is included for all appropriate tests. There were no main effects or interactions involving Sex ($F_s < 1.4$, $P_s > 0.2$); results from these analyses are not reported further. Two participants (1 LTL and 1 RTL) were unable to produce five memories in the Top 5 memory test, but were able to complete the word-cued memory test.

Top 5 Memories

There was a group difference in the recollection of pleasant, unpleasant and neutral memories (i.e. Group \times Valence interaction, $F(4,70) = 2.7$, $P < 0.05$, $\eta^2 = 0.13$). Across all groups, there was a significant effect of valence, $F(2,29) = 11.4$, $P < 0.0001$, $\eta^2 = 0.25$, reflecting greater recall of pleasant and unpleasant compared with neutral memories. Planned contrasts demonstrated that the RTL group recalled significantly fewer unpleasant memories compared with the NC group ($P = 0.01$) and a trend towards fewer unpleasant memories than the LTL group ($P = 0.062$). RTL patients additionally showed a trend towards recall of more pleasant memories compared with the NC ($P = 0.068$) and LTL groups ($P = 0.085$). There was no such differential recall of neutral memories ($P_s > 0.9$; see Fig. 1A).

Word-cued memories

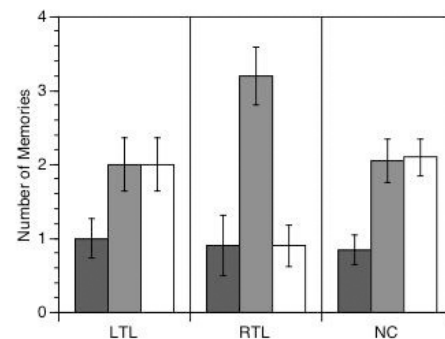
All groups reported well-formed memories to most of the words, though there was a significant group difference in the number of word-cued memories, $F(2,40) = 4.4$, $P < 0.02$; the LTL ($M = 27.2 \pm 1.2$) and RTL ($M = 26.9 \pm 1.3$) groups produced slightly fewer memories than the NC group ($M = 29.9 \pm 0.1$).

Most importantly, there was a significant difference in the pattern of recollection of emotional memories across groups [Group \times Valence interaction: $F(4,74) = 2.79$, $P < 0.05$, $\eta^2 = 0.13$], with the RTL group producing fewer unpleasant memories than both the other groups ($P_s < 0.01$; see Fig. 1B). There was a trend toward greater recall of neutral memories by the RTL group compared with the NC group ($P = 0.08$). There was additionally a significant effect of Valence across all groups, $F(2,74) = 10.1$, $P < 0.0001$, $\eta^2 = 0.21$, in this case indicating greater recall of neutral compared with pleasant or unpleasant memories.

Contribution of pleasantness and intensity to recollections

Previous research has shown a prominent effect of arousal or intensity in enhancing memory (Bradley *et al.*, 1992), and this

A. Top 5 Emotional Memories



B. Word-Cued Memories

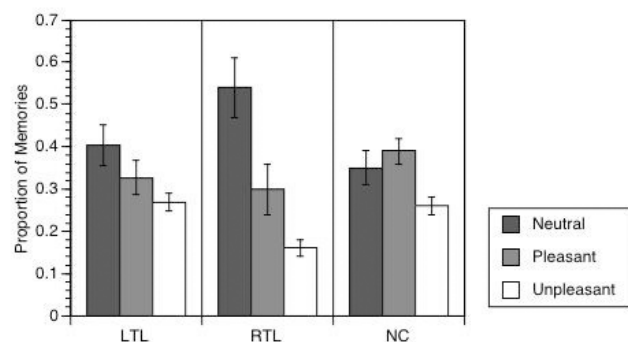


Fig. 1 (A) Number of Top 5 emotional memories rated as neutral, pleasant or unpleasant by each group. (B) Proportion of 30 word-cued memories rated as neutral, pleasant or unpleasant by each group (error bars denote standard error of the mean).

effect may be amygdala-dependent (Kensinger and Corkin, 2004). Hence, we were interested in examining the relative contributions of pleasantness and intensity in the recollection of autobiographical memories. Recollections were classified into four categories: Pleasant/Low Intensity, Unpleasant/Low Intensity, Pleasant/High Intensity and Unpleasant/High Intensity. These classifications were based on participants' ratings. Classification of low versus high pleasantness was accomplished in the same manner as above. For intensity, recollections labelled as 1 or 2 were classified as low intensity and those labelled 6 or 7 were classified as high intensity. It should be noted that this analysis was focused on memories rated relatively extremely on either the pleasantness or intensity scale and excludes memories rated as neutral on the pleasant scale (those rated as 3, 4 or 5) and as neutral on the intensity scale (those rated as 3, 4 or 5). These analyses included the following proportions of total memories for each group: NC group, 35% \pm 18; LTL, 41% \pm 16; RTL, 29% \pm 19. These proportions were not different among the groups ($P > 0.14$). A 3 Group \times 2 Valence (Pleasant versus Unpleasant) \times 2 Arousal (High versus Low) MANOVA was used to examine group differences in recollections. Data from the Top 5 and word-cued memories were combined for this analysis because the split into four pleasantness/intensity categories did not allow for separate analysis of the Top 5 memories (too few memories per category).

Results demonstrated that the groups produced different patterns of recollections across the four categories as evidenced by a significant Group \times Valence \times Arousal interaction, $F(2,40) = 8.4$, $P = 0.001$, $\eta^2 = 0.3$, see Fig. 2. *Post hoc* comparisons demonstrated that the RTL group produced significantly fewer unpleasant/high intensity memories than the NC ($P = 0.001$) and LTL ($P = 0.008$) groups. Additionally, the LTL group produced significantly more pleasant/low intensity memories compared with the RTL group ($P = 0.042$) and marginally more than the NC group ($P = 0.052$). There were also main effects of Valence [$F(1,40) = 6.2$, $P = 0.017$, $\eta^2 = 0.14$] and Arousal [$F(1,40) = 57.3$, $P < 0.0001$, $\eta^2 = 0.59$], though the effect of Arousal was considerably larger than that of Valence, an effect commonly reported (Bradley *et al.*, 1992; Kensinger and Corkin, 2004; Talarico *et al.*, 2004). There was a significant interaction of Group by Arousal, $F(2,40) = 4.0$, $P = 0.03$, $\eta^2 = 0.17$, indicating that while controlling for valence, the comparison group showed more of a benefit from high arousal than did the lobectomy groups. There was no significant Group by Valence interaction [$F(2,40) = 1.3$, $P = 0.3$, $\eta^2 = 0.06$], indicating that controlling for arousal, all groups recalled approximately equal pleasant and unpleasant memories.

Ratings of memories

Ratings were analysed in the same manner as memories, using a 2 Sex \times 3 Group \times 3 Valence ANOVA design separately for Top 5 and word-cued ratings. For Top 5 ratings, several subjects did not rate memories in one of the three valence

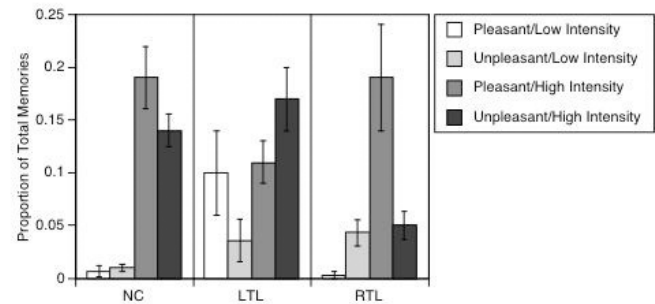


Fig. 2 Proportion of total memories rated as pleasant/low intensity, unpleasant/low intensity, pleasant/high intensity and unpleasant/high intensity by each group (error bars denote standard error of the mean).

categories (e.g. many subjects did not produce any 'neutral' memories during this phase of testing). This has resulted in the exclusion of 6 LTL, 7 RTL and 10 comparison participants from this analysis. In spite of these low numbers, there was a main effect of valence for intensity ratings, with all groups rating the pleasant and unpleasant memories as more intense than neutral memories [$F(2,13) = 3.9$, $P < 0.05$]. There was also a trend towards differential significance ratings across valence categories [$F(2,13) = 3.6$, $P = 0.056$]. There were no differences in the way the different groups rated these memories (no Group by Valence interactions). There was a significant Sex by Valence interaction for intensity ratings, $F(2,13) = 4.4$, $P < 0.05$, with the women rating their pleasant memories as less intense than the men. There were no significant effects or interactions for ratings of novelty, vividness or frequency of rehearsal ($P_s > 0.05$).

For ratings of the word-cued memories, there were significant main effects of valence for intensity, significance, novelty, vividness and frequency of rehearsal, $F_s(2,34) > 16$, $P_s < 0.001$, $\eta^2 > 0.6$, with all groups rating neutral memories lower in all rating scales (see Fig. 3). The groups rated the intensity of their memories differently [Group by Valence interaction: $F(4,68) = 4.8$, $P = 0.002$, $\eta^2 = 0.2$], with the RTL group rating their pleasant memories as higher intensity than their unpleasant memories (see Fig. 3). In contrast, the LTL group rated their unpleasant memories as higher in intensity than their pleasant memories and the healthy comparison group rated the intensity of these memories equally. Similar patterns are observed across the other rating scales, with the RTL group rating their pleasant memories as higher in vividness and significance (see Fig. 3), but these patterns did not reach statistical significance. This pattern is in line with the memory data in that the RTL group report fewer unpleasant memories and now rate their unpleasant memories as lower on various subjective scales. There were no sex differences in the ratings of the memories, but there was a significant Sex by Valence interaction for frequency of rehearsal, with the women reporting greater frequency of rehearsal for pleasant and unpleasant memories compared with men, $F(2,34) = 4.8$, $P < 0.05$, $\eta^2 = 0.2$.

Temporal distribution of memories

Both patient groups recalled an equivalent proportion of memories from before versus after temporal lobectomy (before LTL, mean \pm SE: 0.58 ± 0.07 ; RTL, 0.52 ± 0.08 ; After LTL: 0.42 ± 0.07 , RTL: 0.48 ± 0.08 ; comparison of pre-lobectomy versus post-lobectomy: $F(1,21) < 1$, $P > 0.3$, $\eta^2 = 0.04$; Group \times Time Epoch interaction [$F(1,21) < 1$, $P > 0.5$, $\eta^2 = 0.01$].

The autobiographical memory ‘bump’

There was a clear ‘bump’ in recollection in all groups for the Top 5 memories (see Fig. 4). In order to examine the issue of age at testing on the temporal distribution of memories, we have separately analysed the distribution of Top 5 memories from those participants older than 40 ($Ns = 9, 6$ and 5 for comparison, LTL and RTL, respectively) and younger than 40 ($Ns = 10, 5$ and 5 for comparison, LTL and RTL, respectively). In the younger than 40 group, comparing the number of memories from the first four decades only, there was a significant effect of decade: $F(3,15) = 7.3$, $P < 0.01$, $\eta^2 = 0.6$. In the older than 40 group, comparing decades from 0 to 10 up to >40 , there was similarly a significant effect of decade: $F(4,14) = 4.0$, $P < 0.05$, $\eta^2 = 0.5$. There were no differences between groups in the pattern of recollection across decades (no Group \times Decade interaction: $F_s < 1.5$). Interestingly the

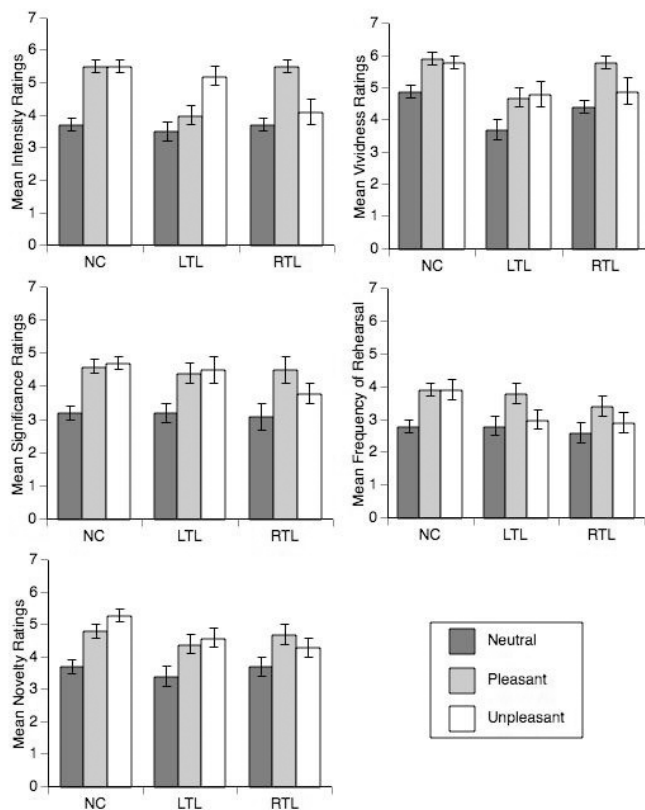
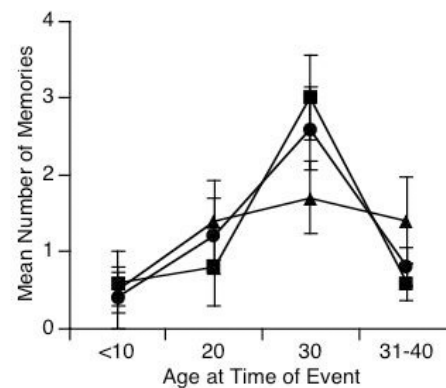


Fig. 3 Ratings of intensity, significance, novelty, vividness and frequency of rehearsal of word-cued memories across groups and valence categories (error bars denote standard error of the mean).

RTL over 40 group reported more memories from the 11 to 20 age range (mean = 2.0) than the 21–30 age range (mean = 0.6), whereas the LTL group showed the opposite pattern (11–20 mean = 0.83; 21–30 mean = 2.2), and the comparison group produced equivalent totals for both age ranges (11–20 mean = 1.3; 21–30 mean = 1.8). These data are based on a small number of participants, but, on average, all groups reported more memories from the 10 to 30 age range than from the other age ranges.

Damage to the medial temporal lobe (on either the left or right) may disrupt memory consolidation of new or recently learned materials. Temporal lobe resection during the ‘bump’ period may alter the pattern of recollection, reducing the number of recollections from the time of the bump due to reduced encoding or consolidation of events during this time period. We tested this possibility by comparing the temporal distribution of Top 5 memories from 11 patients (4 left, 7 right) whose resections occurred between the ages of 10 and 30 to the distribution of memories from 12 patients (8 left, 4 right) whose resections occurred after the 10–30 ‘bump’

A. Younger than 40 Years



B. Older than 40 Years

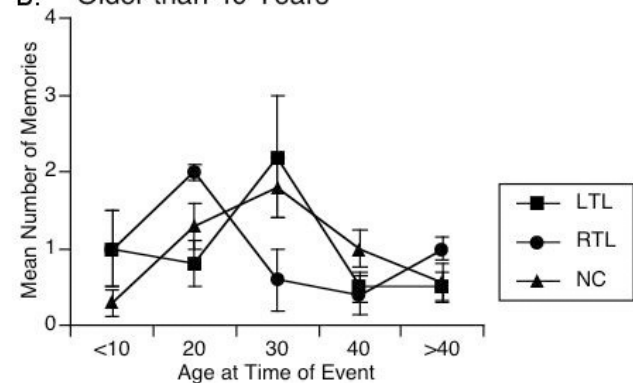


Fig. 4 Temporal distribution of Top 5 emotional memories by participants’ age at the time of event for (A) those younger than 40 (number of participants per group: LTL = 5, RTL = 5, NC = 10). Note that 1 LTL and 3 RTL participants were younger than 30 at the time of testing and so did not contribute to the 30–40 data point and (B) those older than 40 (number of participants per group: LTL = 5, RTL = 4, NC = 9).

period. Results showed that both groups reported more memories from the 10 to 30 period regardless of the timing of their resection [$F(1,19) = 8.8, P = 0.008, \eta^2 = 0.32$] and there was no difference in pattern between the right and left groups [$F(1,19) < 1, P > 0.7$]. These data demonstrate that temporal lobectomy patients show a similar temporal distribution of emotional memories compared with comparison participants in spite of the presence of epilepsy and undergoing brain surgery.

Seizure/medication variables

Variables such as current seizure and medication status are known to influence both anterograde and retrograde memory performance (Lah *et al.*, 2004). To examine the effects of these variables on autobiographical memory measures, we examined potential differences in memory performance based on each patient's seizure history, current seizure status (having had a seizure within the last year or not) and whether or not the patient was currently taking anti-epileptic medication. Those patients with seizure onset before the age of 10 ($N = 13, 4 \text{ RTL}, 9 \text{ LTL}$) did not differ in the total number of memories produced or in the number of pleasant, neutral or unpleasant memories compared with those with seizure onset after the age of 10 ($N = 10, 7 \text{ RTL}, 3 \text{ LTL}$; $t_s(21) < 1.3, P_s > 0.18$). In terms of seizure status, seven patients (4 RTL, 3 LTL) had experienced a seizure within the year prior to testing (mean years since seizure: 0.7 ± 0.5) and 15 patients (7 RTL, 8 LTL) had not had a seizure during that time (mean years since seizure: 6.8 ± 6.5 ; one LTL patient's seizure status is unknown). We analysed the differences between these two groups in terms of the number of memories reported in the Top 5 Memory phase and in the word-cued Memory phase from both before and after brain damage. There was no significant difference in the number of memories produced from before or after temporal lobectomy based on seizure status, $t_s(21) < 1.4, P_s > 0.12$.

Analysis of current medication status revealed that six patients (3 RTL, 3 LTL) were currently not taking anti-epileptic medications and 17 patients (8 RTL, 9 LTL) were taking such medications. As with seizure status, current medication status did not affect memory performance from before or after temporal resection, $t_s(22) < 1, P_s > 0.3$.

Discussion

Although the involvement of the anteromedial temporal lobes in memory for emotional events has been known for some time, there are several outstanding issues about the nature of this involvement that are not well understood. These issues include the influence of laterality, the role of valence and arousal (or intensity), temporal distribution of memories and the correspondence between memories from the laboratory and real life. We addressed these issues by examining the performance of patients with damage to either the right or left medial temporal lobe on tests of emotional autobiographical memories. Results from this study demonstrate a lateralized

effect of medial temporal lobe damage on the recollection of emotional autobiographical events. RTL patients showed a positive bias in their recollections: they reported fewer unpleasant memories, and specifically fewer unpleasant/high intensity memories, compared with the other groups. The LTL group, in contrast, reported an equivalent number of pleasant and unpleasant memories, as did the NC group. The LTL group also rated more of their pleasant memories as low intensity. Additionally, all participants reported the bulk of their Top 5 most emotional memories from the time period between the ages of 10 and 30, suggesting that temporal lobe damage—on either the right or left—does not alter the normal temporal distribution of emotional autobiographical memory recollection. These findings provide information on the correspondence between real-life memories and those for laboratory events by showing that damage to the medial temporal lobe—specifically on the right side—positively biases memory reports for real-life emotional events.

Neuroanatomical considerations

An important question raised by our findings concerns the precise neural structures whose damage might be responsible for the findings. Results from the present study are in line with recent findings from our laboratory demonstrating that patients with bilateral medial temporal lobe damage including the amygdala, but not those with hippocampal damage only, show a positivity bias in their autobiographical recollections (Buchanan *et al.*, 2005). That study showed that patients with bilateral amygdala and hippocampal damage reported more pleasant than unpleasant autobiographical memories, they rated their unpleasant memories as less intense than the other groups, and used fewer unpleasant words in describing their memories. The patients with damage to the hippocampus only (who did not have reduced amygdala volumes) did not show this positivity bias. The commonality, then, among those patients producing a positive bias in autobiographical memory is damage to the right anteromedial temporal lobe including the amygdala. Together, results from these two studies suggest that the right amygdala—regardless of the integrity of the left amygdala—may be a necessary component of the neural circuitry critical for the recollection of unpleasant, highly intense autobiographical experiences. Although in both studies the damage was not limited to the amygdala, but included parts of anterior hippocampus and the surrounding cortex (*see* Table 1), patients with bilateral damage to the hippocampus sparing the amygdala did not show this positivity bias (Buchanan *et al.*, 2005). This suggests that it is specifically the right amygdala that is mediating the effects we report here. Previous work by Markowitsch *et al.* (1998, 2000) has suggested a lateralization of amygdala activity in the retrieval of autobiographical memories (Fink *et al.*, 1996). Our results are the first to link the right amygdala with a positive bias in autobiographical retrieval.

Although both patient groups had variable impairments in general semantic knowledge (Famous Faces and Landmark

Recognition tests; see Table 2) and verbal intelligence, there was only a trend towards group differences between left and right lobectomy groups, with the left-sided subjects showing poorer performance. Thus, both the specificity of the autobiographical memory pattern in patients with damage to the right medial temporal lobe and the specificity for the emotional valence of the autobiographical material are not accounted for solely by more general memory dysfunction nor by differences in IQ. These differences, in addition, are not accounted for by differences in temporal lobe volume, as both groups showed comparable volumes of the surgically excised and intact temporal lobes (see Table 1). Rather, we believe that these differences reflect a separate, specific dysfunction that arises from damage to valence-specific retrieval mechanisms that draw on structures in the right medial temporal lobe.

It is unclear from these results whether the RTL patients' positivity bias reflects altered memory retrieval processes or impaired recognition of unpleasant experiences as negative events. Although memory deficits are reported following RTL (Pillon *et al.*, 1999; Viskontas *et al.*, 2000; Lah *et al.*, 2004), the reason for retrieval of unpleasant memories to be specifically affected in these patients is unknown. Viskontas *et al.* (2000) showed that patients with either right-sided or left-sided epilepsy or excisions showed reduced 'descriptive richness and specificity in time and place' of episodic memories, but no laterality effects were reported. These authors did not, however, specifically address the emotional nature of memories in their patient groups. Previous work with RTL patients has not shown a positive bias in the learning and memory for emotional stimuli in the laboratory (Buchanan *et al.*, 2001). Another possibility is that the observed pattern is due to an inability to recognize negative emotional experiences as unpleasant or highly arousing. Previous research in patients with unilateral temporal lobectomy suggests that damage to the right temporal lobe alters the recognition of negative emotional stimuli. Such patients can have difficulty recognizing facial expressions of negative, or withdrawal-related emotions, especially fearful expressions (Anderson *et al.*, 2000; Adolphs *et al.*, 2001). This research, in combination with the current results, suggests a role of the right anteromedial temporal lobe in recognition of negative emotion from environmental cues such as facial expressions as well as from an individual's past experience. Previous research (Adolphs *et al.*, 2000; Winston *et al.*, 2003) has suggested a right hemisphere network involved in the recognition of emotions in others that relies upon the recognition of self-generated emotions. Adolphs *et al.* (2000) suggested that the right amygdala, right somatosensory cortex and right visual cortices might constitute a network involved in the recognition of emotions through the simulation of internal feeling states. Perhaps damage to this right hemisphere network in the RTL patients—specifically in the right medial temporal lobe—affected their recognition of negative emotional events from their own memories.

Valence, intensity and memory

Research on emotional memory has shown that the intensity, or arousal of the to-be-remembered stimulus is a better predictor of memory than is valence in both laboratory studies (Bradley *et al.*, 1992) and studies of autobiographical memory (Talarico *et al.*, 2004). Although both highly pleasant and highly unpleasant experiences are better remembered than neutral experiences, the construct of arousal or intensity provides a more parsimonious account of the influence of emotion on memory. Those experiences rated as high intensity—regardless of valence—are those most likely to be recollected. In fact, when controlling for the effects of arousal, the effect of valence on autobiographical recollections was no longer significant in the current investigation. The current results suggest a differential role of the right versus the left anteromedial temporal region in the recollection of pleasant/high intensity memories and unpleasant/high intensity memories. Whereas the RTL patients recollected more memories rated as pleasant/high intensity, the LTL group recalled fewer of these memories and tended to recall more unpleasant/high intensity memories and more pleasant/low intensity memories. The left temporal lobe may be necessary for the recollection of pleasant/high intensity experiences. Conversely, the right temporal lobe may be necessary for the recollection of unpleasant/high intensity experiences. Damage to either side alters the pattern of emotional recollection, suggesting that the anteromedial temporal lobe structures are part of a neural network necessary for the recollection of emotionally intense memories.

Previous works examining the influence of valence and arousal in memory encoding have suggested a preferential role for the amygdala in the processing of intensity. Learning research in rodents has suggested a parallel system of aversive and appetitive conditioning through the operation of amygdaloid nuclei subsystems (Everitt *et al.*, 2003), suggesting that these structures are more responsive to the intensity of stimuli than valence *per se*. Similarly in human functional imaging research, Hamann and co-workers (Hamann and Mao, 2002; Hamann *et al.*, 2002) have demonstrated increased amygdala activity in response to highly arousing positive and highly arousing negative stimuli. Additionally, Kensinger and Corkin (2004) have demonstrated that the intensity of a verbal stimulus determines both the amygdala response and the subsequent memory of that stimulus whereas memory for less intense, negatively valenced words was associated with prefrontal activity during encoding. The laterality of amygdala activity has been equivocal in these studies, making direct comparison with the lateralized pattern of the current results unclear (Baas *et al.*, 2004). Previous work from patients with anteromedial temporal lobe lesions has addressed the relationships among valence, intensity and lateralization. Adolphs *et al.* (2001) showed that RTL patients were impaired on rating the intensity expressed in facial expressions of fear, but not other emotions. Similarly, Adolphs *et al.* (1999) described a patient with bilateral

amygdala damage who showed an impairment in recognizing the emotional arousal in faces and verbal stimuli that expressed unpleasant, but not pleasant, emotions (Adolphs *et al.*, 1999). The current research, along with previous findings suggests an interaction between intensity (or arousal) and valence within the anteromedial temporal lobe: in general, patients with right-sided excisions are unable to recollect the high intensity unpleasant experiences from their past, whereas patients with left-sided damage show reduced recollection of pleasant high intensity memories. Future research examining this interaction in lesion or functional neuroimaging applications will be important to fully understand the dynamics of intensity and valence processing in the medial temporal lobes.

Temporal distribution of autobiographical memories

Results examining the temporal distribution of memories demonstrated that temporal lobectomy—both right-sided and left-sided—patients reported an equivalent number of memories from before and after surgery. Examination of the temporal distribution of Top 5 emotional memories from all groups showed a pronounced ‘bump’ (Rubin *et al.*, 1998*b*) in memories formed between the ages of 10 and 30. This result is in line with that from patients with bilateral medial temporal lobe damage who also showed the bump in recollection of Top 5 Emotional Memories (Buchanan *et al.*, 2005). Research from Rubin and co-workers has demonstrated that the autobiographical memory ‘bump’ for emotional memories is a robust phenomenon (Rubin and Schulkind, 1997; Rubin *et al.*, 1998). Interestingly, many of the patients in our current study (11 out of 23) had their temporal lobectomy surgery during this age range and yet showed the normal ‘bump’ pattern. Recent work by Rubin and Berntsen (2003) has suggested that the bump may be due to cultural expectations of what happens at certain time periods in an individual’s life rather than determined by some biological mechanism. It is important to note, however, that our results are based on a relatively small number of patients from a restricted age range and should be considered preliminary. Specifically, the patients range in age from 24 to 59 years of age. Prior work on the distribution of autobiographical memories has shown that the bump in recollections for the 10–30 age range is most pronounced in older participants, especially for word-cued memories, for which we did not find a bump in recollections for these participants. Follow-up research could address the temporal distribution of these participants at different time points to examine the pattern of autobiographical recollections following temporal lobe damage with advancing age.

Previous work has linked successful memory retrieval—including both autobiographical and semantic memory—with the integrity of the neocortex, whereas medial temporal lobe structures are more important for the recollection of recent events (Graham and Hodges, 1997; Rubin

and Greenberg, 1998; Bayley *et al.*, 2005). Results from this study suggest that the ability to vividly recollect unpleasant memories from remote and recent time periods depends on portions of the right temporal lobe. Since the RTL patients had damage to both medial and lateral aspects of the temporal lobe, it is not possible from these data to say that one area is more involved in remote memory recollection than the other. Measures of semantic memory (Famous Faces and Landmarks) and verbal IQ from the neuropsychological battery (*see* Table 2) were slightly lower in the LTL group than the RTL group. These differences in neuropsychological performance were not, however, related to differences in the volumes of the temporal lobe (nor to the individual volumes of the hippocampus or amygdala) between the groups. Future work should address the relative contributions of amygdala, hippocampus and lateral temporal cortex in the recollection of emotional experiences.

Sex differences in emotional memory

Previous work has demonstrated sex differences in neural activity (Cahill *et al.*, 2001, 2004*b*; Canli *et al.*, 2002) and behavioural performance (Cahill *et al.*, 2004*a*) during tasks assessing emotional memory. We addressed the issue of sex differences in this study by including approximately equal numbers of men and women in each participant group and including sex as a factor in our analyses. The results did not indicate a reliable sex difference in performance in any of the tasks, both in terms of the number of memories produced as well as in the subjective ratings. These findings correspond with our previously reported work in temporal lobectomy patients, in which no effect of sex was found on performance of emotional or memory tasks (Adolphs *et al.*, 2001; Buchanan *et al.*, 2001; Buchanan *et al.*, 2004). It is our impression that this pattern reflects the large effect of brain lesion on emotional memory performance that overwhelms the relatively smaller effect of sex, rather than a complete absence of a sex effect *per se*. Future work testing larger numbers of men and women participants could address the tenability of this proposition.

Summary

A right-sided dominance for the neural correlates of the recognition and expression of negative emotions has been found in numerous laboratory studies on the neuropsychology of emotion. The current findings extend this pattern by demonstrating that RTL patients show a positive bias in the recollection of their real-life emotional memories. These patients produced fewer unpleasant memories compared with patients with left medial temporal damage and compared with healthy comparison participants. Additionally, these findings extend previously reported patterns of emotional memory performance following medial temporal lobe damage beyond laboratory-based memories, into the realm of real-world memories. The present study was an initial attempt at better understanding the neural basis of the emotional

autobiographical memory recollection. The various issues addressed in this work—laterality, valence, intensity and temporal distribution of recollections—warrant more attention in future research.

Acknowledgements

The authors would like to thank Benjamin R. Lewis and Kodi Scheer for assistance in data collection. This work was supported by an NRSA from NIA to T.W.B., NINDS Program Project Grant P01 NS19632 and NIMH R01 067681.

References

- Adolphs R, Cahill L, Schul R, Babinsky R. Impaired declarative memory for emotional material following bilateral amygdala damage in humans. *Learn Mem* 1997; 4: 291–300.
- Adolphs R, Russell JA, Tranel D. A role for the human amygdala in recognizing emotional arousal from unpleasant stimuli. *Psychol Sci* 1999; 10: 167–71.
- Adolphs R, Damasio H, Tranel D, Cooper G, Damasio AR. A role for somatosensory cortices in the visual recognition of emotion as revealed by three-dimensional lesion mapping. *J Neurosci* 2000; 20: 2683–90.
- Adolphs R, Tranel D, Damasio H. Emotion recognition from faces and prosody following temporal lobectomy. *Neuropsychology* 2001; 15: 396–404.
- Allen JS, Damasio H, Grabowski TJ. Normal neuroanatomical variation in the human brain: an MRI-volumetric study. *Am J Phys Anthropol* 2002; 118: 341–58.
- Anderson AK, Spencer DD, Fulbright RK, Phelps EA. Contribution of the anteromedial temporal lobes to the evaluation of facial emotion. *Neuropsychology* 2000; 14: 526–36.
- Baas D, Aleman A, Kahn RS. Lateralization of amygdala activation: a systematic review of functional neuroimaging studies. *Brain Res Brain Res Rev* 2004; 45: 96–103.
- Barr WB. Examining the right temporal lobe's role in nonverbal memory. *Brain Cogn* 1997; 35: 26–41.
- Barr WB, Goldberg E, Wasserstein J, Novelly RA. Retrograde amnesia following unilateral temporal lobectomy. *Neuropsychologia* 1990; 28: 243–55.
- Bayley PJ, Hopkins RO, Squire LR. Successful recollection of remote autobiographical memories by amnesic patients with medial temporal lesions. *Neuron* 2003; 38: 135–44.
- Bayley PJ, Gold JJ, Hopkins RO, Squire LR. The neuroanatomy of remote memory. *Neuron* 2005; 46: 799–810.
- Beatty WW, Salmon DP, Bernstein N, Butters N. Remote memory in a patient with amnesia due to hypoxia. *Psychol Med* 1987; 17: 657–65.
- Berntsen D, Rubin DC. Emotionally charged autobiographical memories across the life span: the recall of happy, sad, traumatic, and involuntary memories. *Psychol Aging* 2002; 17: 636–52.
- Bradley MM, Lang PJ. Affective norms for English words. Gainesville, FL: NIMH Center for the Study of Emotion and Attention; 1999.
- Bradley MM, Greenwald MK, Petry MC, Lang PJ. Remembering pictures: pleasure and arousal in memory. *J Exp Psychol Learn Mem Cogn* 1992; 18: 379–90.
- Buchanan TW, Adolphs R. The neuroanatomy of emotional memory in humans. In: Reisberg D, Hertel P, editors. *Memory and emotion*. New York: Oxford University Press; 2004. p. 42–75.
- Buchanan TW, Denburg NL, Tranel D, Adolphs R. Verbal and nonverbal emotional memory following unilateral amygdala damage. *Learn Mem* 2001; 8: 326–35.
- Buchanan TW, Tranel D, Adolphs R. Anteromedial temporal lobe damage blocks startle modulation by fear and disgust. *Behav Neurosci* 2004; 118: 429–37.
- Buchanan TW, Tranel D, Adolphs R. Emotional autobiographical memories in amnesic patients with medial temporal lobe damage. *J Neurosci* 2005; 25: 3151–60.
- Cahill L. Modulation of long-term memory storage in humans by emotional arousal: adrenergic activation and the amygdala. In: Aggleton J, editor. *The amygdala*. Oxford: Oxford University Press; 2000. p. 425–46.
- Cahill L, Babinsky R, Markowitsch HJ, McGaugh JL. The amygdala and emotional memory. *Nature* 1995; 377: 295–6.
- Cahill L, Haier RJ, White NS, Fallon J, Kilpatrick L, Lawrence C, et al. Sex-related difference in amygdala activity during emotionally influenced memory storage. *Neurobiol Learn Mem* 2001; 75: 1–9.
- Cahill L, Gorski L, Belcher A, Huynh Q. The influence of sex versus sex-related traits on long-term memory for gist and detail from an emotional story. *Conscious Cogn* 2004a; 13: 391–400.
- Cahill L, Uncapher M, Kilpatrick L, Alkire MT, Turner J. Sex-related hemispheric lateralization of amygdala function in emotionally influenced memory: an fMRI investigation. *Learn Mem* 2004b; 11: 261–6.
- Canli T, Desmond JE, Zhao Z, Gabrieli JD. Sex differences in the neural basis of emotional memories. *Proc Natl Acad Sci USA* 2002; 99: 10789–94.
- Convit A, McHugh P, Wolf OT, de Leon MJ, Bobinski M, De Santi S, et al. MRI volume of the amygdala: a reliable method allowing separation from the hippocampal formation. *Psychiatry Res* 1999; 90: 113–23.
- Conway MA. Cognitive-affective mechanisms and processes in autobiographical memory. *Memory* 2003; 11: 217–24.
- Crovitz H, Schiffman H. Frequency of episodic memories as a function of their age. *Bull Psychon Soc* 1974; 4: 517–8.
- Duvernoy HM. *The human hippocampus: an atlas of applied anatomy*. New York: Springer-Verlag; 1988.
- Everitt BJ, Cardinal RN, Parkinson JA, Robbins TW. Appetitive behavior: impact of amygdala-dependent mechanisms of emotional learning. *Ann N Y Acad Sci* 2003; 985: 233–50.
- Fink GR, Markowitsch HJ, Reinkemeier M, Bruckbauer T, Kessler J, Heiss WD. Cerebral representation of one's own past: neural networks involved in autobiographical memory. *J Neurosci* 1996; 16: 4275–82.
- Frank RJ, Damasio H, Grabowski TJ. Brainvox: an interactive, multimodal visualization and analysis system for neuroanatomical imaging. *Neuroimage* 1997; 5: 13–30.
- Funayama ES, Grillon C, Davis M, Phelps EA. A double dissociation in affective modulation of startle in humans: effects of unilateral temporal lobectomy. *J Cogn Neurosci* 2001; 13: 721–9.
- Games PA, Howell JF. Pairwise multiple comparison procedures with unequal n's and/or variances. *J Educ Stat* 1976; 1: 113–25.
- Gold PE, Hankins L, Edwards RM, Chester J, McGaugh JL. Memory interference and facilitation with posttrial amygdala stimulation: effect on memory varies with footshock level. *Brain Res* 1975; 86: 509–13.
- Graham KS, Hodges JR. Differentiating the roles of the hippocampal complex and the neocortex in long-term memory storage: evidence from the study of semantic dementia and Alzheimer's disease. *Neuropsychology* 1997; 11: 77–89.
- Hamann S, Mao H. Positive and negative emotional verbal stimuli elicit activity in the left amygdala. *Neuroreport* 2002; 13: 15–9.
- Hamann SB, Cahill L, McGaugh JL, Squire LR. Intact enhancement of declarative memory for emotional material in amnesia. *Learn Mem* 1997a; 4: 301–9.
- Hamann SB, Cahill L, Squire LR. Emotional perception and memory in amnesia. *Neuropsychology* 1997b; 11: 104–13.
- Hamann SB, Ely TD, Hoffman JM, Kilts CD. Ecstasy and agony: activation of the human amygdala in positive and negative emotion. *Psychol Sci* 2002; 13: 135–41.
- Jones RD, Grabowski T, Tranel D. The neural basis of retrograde memory: evidence from positron emission tomography for the role of non-mesial temporal lobe structures. *Neurocase* 1998; 4: 471–9.
- Jones RD, Mitchell R, Tranel D. Knowing 'what' and knowing 'when': memory dissociations linked to the basal forebrain. *J Int Neuropsychol Soc* 2000; 6: 112.

- Kensinger EA, Corkin S. Two routes to emotional memory: distinct neural processes for valence and arousal. *Proc Natl Acad USA* 2004; 101: 3310–5.
- Kopelman MD, Stanhope N, Kingsley D. Retrograde amnesia in patients with diencephalic, temporal lobe, or frontal lesions. *Neuropsychologia* 1999; 37: 939–58.
- LaBar KS, Phelps EA. Arousal-mediated memory consolidation: role of the medial temporal lobe in humans. *Psychol Sci* 1998; 9: 490–3.
- Lah S, Grayson S, Lee T, Miller L. Memory for the past after temporal lobectomy: impact of epilepsy and cognitive variables. *Neuropsychologia* 2004; 42: 1666–79.
- Markowitsch HJ. Differential contribution of right and left amygdala to affective information processing. *Behav Neurol* 1998; 11: 233–44.
- Markowitsch HJ, Thiel A, Reinkemeier M, Kessler J, Koyuncu A, Heiss WD. Right amygdalar and temporofrontal activation during autobiographic, but not during fictitious memory retrieval. *Behav Neurol* 2000; 12: 181–90.
- McGaugh JL. *Memory and emotion: the making of lasting memories*. New York: Columbia University Press; 2003.
- Milner B. Amnesia following operation on the temporal lobes. In: Whitty CWM, Zangwill OL, editors. *Amnesia*. London: Butterworths; 1966; p. 109–33.
- Milner B. Interhemispheric differences in the localization and psychological processes in man. *Br Med Bull* 1971; 27: 272–7.
- Nadel L, Moscovitch M. Memory consolidation, retrograde amnesia and the hippocampal complex. *Curr Opin Neurobiol* 1997; 7: 217–27.
- Pillon B, Bazin B, Deweer B, Ehrle N, Baulac M, Dubois B. Specificity of memory deficits after right or left temporal lobectomy. *Cortex* 1999; 35: 561–71.
- Richardson MP, Strange BA, Dolan RJ. Encoding of emotional memories depends on amygdala and hippocampus and their interactions. *Nat Neurosci* 2004; 7: 278–85.
- Rubin D, Schulkind M. Distribution of important and word-cued autobiographical memories in 20-, 35-, and 70-year-old adults. *Psychol Aging* 1997; 12: 524–35.
- Rubin DC, Greenberg DL. Visual memory-deficit amnesia: a distinct amnesic presentation and etiology. *Proc Natl Acad Sci USA* 1998; 95: 5413–6.
- Rubin DC, Rahhal TA, Poon LW. Things learned in early adulthood are remembered best. *Mem Cognit* 1998; 26: 3–19.
- Rubin DC, Berntsen D. Life scripts help to maintain autobiographical memories of highly positive, but not highly negative, events. *Mem Cognit* 2003; 31: 1–14.
- Scoville WB, Milner B. Loss of recent memory after bilateral hippocampal lesions. *J Neurol Neurosurg Psychiatry* 1957; 20: 11–21.
- Silberman EK, Weingartner H. Hemispheric lateralization of functions related to emotion. *Brain Cogn* 1986; 5: 322–53.
- Szabo CA, Xiong J, Lancaster JL, Rainey L, Fox P. Amygdalar and hippocampal volumetry in control participants: differences regarding handedness. *Am J Neuroradiol* 2001; 22: 1342–5.
- Talarico JM, LaBar KS, Rubin DC. Emotional intensity predicts autobiographical memory experience. *Mem Cognit* 2004; 32: 1118–32.
- Tranel D. Theories of clinical neuropsychology and brain-behavior relationships: lurid and beyond. In: Ricker JH, editor. *Handbook of clinical neuropsychology*. Amsterdam: Swets and Zeitlinger; 2005a. In press.
- Tranel D. Impaired naming of unique landmarks is associated with left temporal polar damage. *Neuropsychology*, 2005b. In press.
- Tranel D, Jones RD. Knowing what and knowing when. *J Clin Exp Neuropsychol* 2005; In press.
- Tranel D, Enekechi N, Manzel K. A test for measuring recognition and naming of landmarks. *J Clin Exp Neuropsychol* 2005; 27: 102–26.
- Tranel D, Damasio H, Damasio AR. Amnesia caused by herpes simplex encephalitis, infarctions in basal forebrain, and anoxia/ischemia. In: Grafman FBJ, editor. *Handbook of neuropsychology*. Vol. 2. Amsterdam: Elsevier Science; 2000. p. 85–110.
- Viskontas IV, McAndrews MP, Moscovitch M. Remote episodic memory deficits in patients with unilateral temporal lobe epilepsy and excisions. *J Neurosci* 2000; 20: 5853–7.
- Winston JS, O'Doherty J, Dolan RJ. Common and distinct neural responses during direct and incidental processing of multiple facial emotions. *Neuroimage* 2003; 20: 84–97.
- Zola-Morgan S, Cohen NJ, Squire LR. Recall of remote episodic memory in amnesia. *Neuropsychologia* 1983; 21: 487–500.