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Functional neuroimaging of autobiographical memory

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Functional neuroimaging studies of autobiographical memory have grown dramatically in recent years. These studies are important because they can investigate the neural correlates of processes that are difficult to study using laboratory stimuli, including: (i) complex constructive processes, (ii) recollective qualities of emotion and vividness, and (iii) remote memory retrieval. Constructing autobiographical memories involves search, monitoring and self-referential processes that are associated with activity in separable prefrontal regions. The contributions of emotion and vividness have been linked to the amygdala and visual cortex respectively. Finally, there is evidence that recent and remote autobiographical memories might activate the hippocampus equally, which has implications for memory-consolidation theories. The rapid development of innovative methods for eliciting personal memories in the scanner provides the opportunity to delve into the functional neuroanatomy of our personal past.

Introduction

Autobiographical memory (AM) is what is usually meant by the term 'memory' – the ability to remember past events from one's own life. The number of functional neuroimaging studies that investigate AM has increased rapidly in recent years. The results of these studies expand functional neuroimaging studies of laboratory memory (LM) in at least three domains. First, AM studies can inform our understanding of the complex constructive nature of AM retrieval, which is difficult to capture in the retrieval of simple laboratory stimuli. Second, AM studies can investigate recollective qualities of event memories that are often difficult to study in LM, such as emotion and vividness. Third, AM studies can investigate the retrieval of remote memories, which cannot be created in the laboratory but which is a crucial issue for theories of memory consolidation. This review focuses on the importance of functional neuroimaging investigations of AM with respect to these three domains.

Constructing autobiographical memories

Although AMs are often retrieved involuntarily [1], functional neuroimaging studies of AM have focused on voluntary retrieval processes that involve control operations interacting with different forms of memory. For example, try to remember the last time you had Chinese food. Unless the event occurred recently, recovering an AM requires a protracted and effortful memory search process guided by semantic knowledge about the world (e.g. Chinese restaurants in your city) and about your own life (e.g. you like fancy restaurants), and controlled by inferential processes (e.g. you probably went with Claire, who loves Chinese food). As the search narrows, an event that fits the description might be found (e.g. dinner at *Chopstix* with Peter and Claire), and this event will typically include emotions and visual images (see 'Recollective qualities of autobiographical memory: emotion and vividness'). Sometimes, recovered AMs do not fit the target (e.g. *Chopstix* was not the last one) or the information retrieved is partially incorrect (e.g. it was Keith, not Peter), and monitoring processes must detect these errors. Because the final target of AM construction is a personal memory, it is dependent on self-referential processing. Functional neuroimaging studies have associated these various constructive processes with different prefrontal cortex (PFC) regions: in particular, memory search and controlled retrieval processes involving left lateral PFC, monitoring processes with ventromedial PFC and self-referential processes with medial PFC.

The link between memory search and controlled retrieval processes in AM and lateral PFC regions was detected by an early positron emission tomography study [2] that found activation in this area (Figure 1a) when comparing AM retrieval with LM retrieval (generic cues method; Box 1). Although activation differences between these tasks might reflect many factors [3], the link between AM and activations in lateral PFC and other brain regions was supported by subsequent meta-analyses [4,5]. Lateral PFC regions are assumed to be organized hierarchically, with ventrolateral PFC involved in cue specification and controlled retrieval of information from posterior regions, and dorsolateral PFC manipulating the products of retrieval in working memory [6]. For example, Steinvorth *et al.* found activity in both dorsolateral and ventrolateral PFC during an initial search period for remote events when comparing AM retrieval with LM retrieval, whereas only dorsolateral PFC activity remained online during reminiscence [7]. These results are consistent with the idea that AM construction is an iterative process [8]. Lateral PFC activity that is involved in memory search and controlled retrieval is predominantly left-lateralized [4,5], which is thought to reflect the contribution of semantic information to AM (Box 2), consistent with a left-lateralized pattern of activation in PFC irrespective of the nature of the eliciting cue [9].

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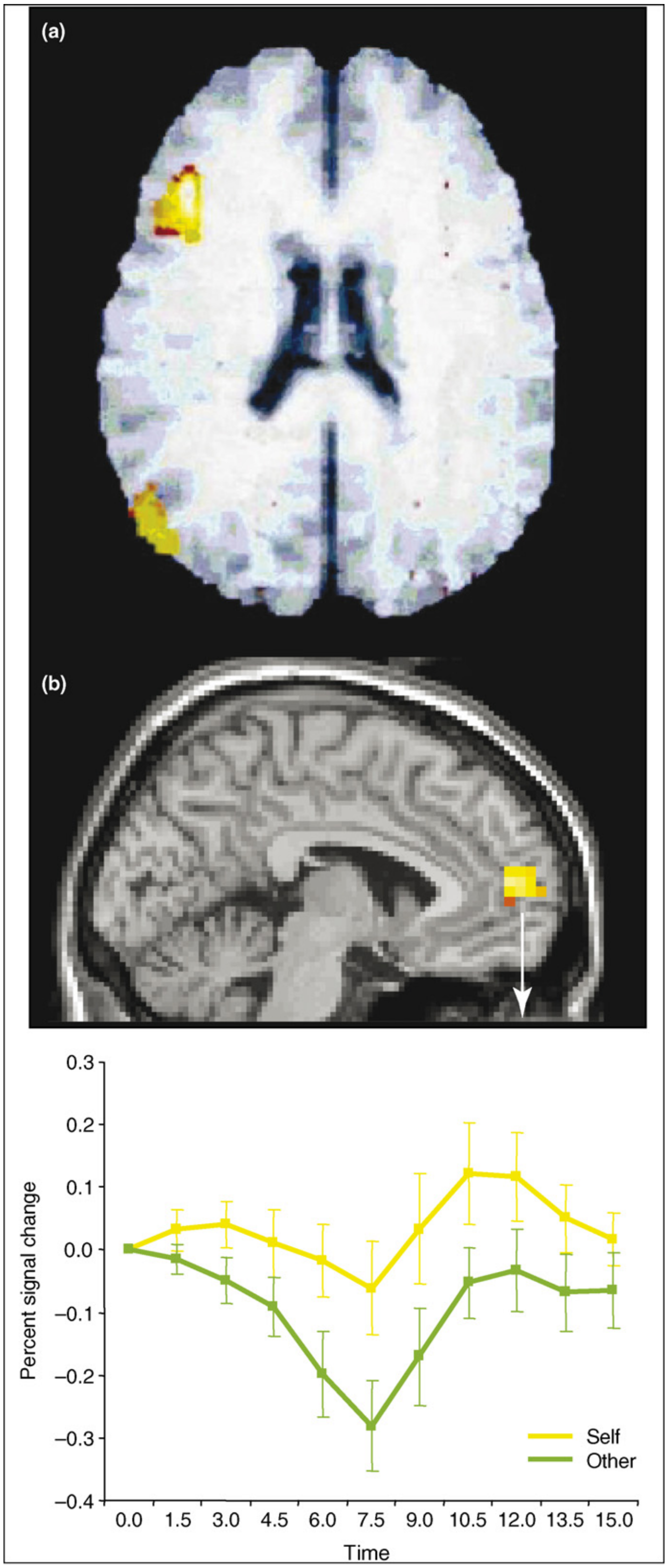

Figure 1. Prefrontal cortex (PFC) regions involved in constructive processes during AM retrieval. **(a)** Left lateral PFC regions, including dorsolateral areas, were associated with search processes in a comparison of AM and LM tasks [2]. Reprinted from Ref. [2], by kind permission of Psychology Press. **(b)** The link between medial PFC and self-referential processing was supported by a study that found greater activation in this region when participants recognized photos taken by themselves (self) compared with photos taken by other participants (other) [3]. Reprinted, with permission, from Ref. [3].

Monitoring processes during AM have been associated with activations in ventromedial PFC [10]. For example, Graham *et al.* found greater activity in ventromedial PFC associated with the recall of AM compared with semantic memory [11]. It has been suggested that AM involves a type of monitoring that is different from the one typically required by LM, which has been linked to right dorsolateral PFC [12]. According to Moscovitch and collaborators [13], LM tasks typically require elaborate, conscious monitoring, whereas AMs normally involve a quick, intuitive and pre-conscious form of monitoring called feeling-of-rightness (FOR). Consistent with the FOR hypothesis, a meta-analysis found that ventromedial PFC regions tend to be more frequent in AM than in LM studies [10]. Although ventromedial PFC activations are not typical in LM studies, they can be found during illusory recognition [14]. Moreover, ventromedial PFC damage has been associated with confabulation [15].

Self-referential processing is an integral, defining component of AM and has been linked to activations in medial PFC [3,16]. For example, in a study in which participants viewed photos of familiar locations [3], medial PFC was differentially more active when participants recognized photos taken by themselves (self) than photos taken by other participants (other). This is consistent with other functional neuroimaging evidence that links medial PFC to self-referential processing [17,18]. Although described for simplicity as 'activations', these differences typically occur because the medial PFC region is 'less deactivated' in the condition that involves self-referential processing than in the control condition [17,18]. This was also found in the aforementioned AM study (Figure 1b). One explanation of this phenomenon is that self-referential processing is part of a 'default state' of the brain [17].

In sum, functional neuroimaging studies of AM have associated constructive retrieval processes with different brain regions. Search processes have been associated with lateral PFC regions, monitoring processes in the form of FOR have been associated with ventromedial PFC regions, and self-referential processes have been associated with medial PFC. These constructive processes eventually lead to remembering of specific events, involving two important recollective qualities: emotion and visual imagery.

Recollective qualities of autobiographical memory: emotion and vividness

AMs are ideal for investigating the contribution of emotion and vividness to the neural correlates of event memory because they often involve rich emotional content and vivid sensory details [19], which are qualities that are typically absent in LMs. Functional neuroimaging studies of emotion in AM have found that, in contrast to the typical left-lateralized activation pattern for neutral AMs, emotional AMs tend to elicit right-lateralized or bilateral activations [20–23], consistent with evidence that patients who have right hemisphere damage generate AMs that are independently rated as containing less emotion [24].

Like the literature on cognitive neuroscience of emotional memory [25], emotional AMs have been associated with activation in the amygdala [21,22,26,27]. Emotional AMs are also associated with greater activity

Box 1. Methods for investigating autobiographical memory using functional neuroimaging

Four main methods have been used to investigate autobiographical memory (AM) using functional neuroimaging (Table I). In the generic cues method, AMs are generated from novel retrieval cues (e.g. 'table') [60]. Although the memories elicited by generic cues are not necessarily emotional or significant, they tend to be 'fresh', unrehearsed memories, which are more purely episodic than memories that have been retrieved many times in the past. Constraining retrieval cues (e.g. childhood memories for the word 'table') or by using cues known to elicit memories of certain emotional quality (e.g. 'prom') can produce a more restricted sample of memories as needed. The need for longer trials might be a disadvantage if memory search is not a process of interest.

In the pre-scan interview method, AMs are elicited by cues that refer to specific events (e.g. visiting the zoo in San Diego). These cues are typically collected in a pre-scan interview during which participants generate memories and rate them according to various scales (e.g. age, emotion and vividness). The memories that are retrieved in the scanner can be controlled using pre-scan ratings, and trials can be short because retrieval cues identify specific memories. The main disadvantage is that the additional retrieval practice might alter the original phenomenological properties of the memories. This problem might be attenuated by interposing a substantial time interval between pre-scan and scan sessions [61]. Another disadvantage is that participants might self-select only well-rehearsed and therefore semanticized AMs: AMs that have lost their episodic quality and are less likely to be re-experienced (Box 2).

In the independent sources method, cues are generated by relatives or friends. This method combines the advantages of the previous two methods, but a disadvantage is that participants might be unable to remember the event provided by the sources or might remember it differently.

Finally, in the prospective method, participants are asked to keep a record of events in their lives to be used as retrieval cues in the scanner. The main advantage of the prospective method is that it enables accuracy assessment, which is important given that brain activity in medial temporal and other regions tends to vary as a function of retrieval accuracy [62]. However, the prospective method does not enable the study of remote memories and, in some cases, it might interfere with the natural encoding of AMs.

Table I. Methods for investigating autobiographical memory in functional neuroimaging

Methods	Study examples	Advantages	Disadvantages
Generic cues (e.g. Galton-Crovitz test)	Conway *et al.* [2] Graham *et al.* [11]	Retrieval in scanner not contaminated by recent retrieval episodes Memory search can be investigated Often unpracticed 'fresh' memories	Little control over the age and content of retrieved memories Memory search requires long trials Accuracy cannot be assessed
Pre-scan interview	Fink *et al.* [21] Maguire *et al.* [48] Greenberg *et al.* [30]	Some control over the age and content of retrieved memories Short trials can be used	Retrieval in scanner contaminated by retrieval in the pre-scan session Memory search cannot be studied Accuracy cannot be assessed
Independent sources	Gilboa *et al.* [38] Steinvorth *et al.* [7]	Retrieval in scanner not contaminated by recent retrieval episodes Some control over the age and content of retrieved memories	Events might not be retrievable Accuracy cannot be assessed
Prospective method	Levine *et al.* [67] Cabeza *et al.* [3]	Retrieval in scanner not contaminated by recent retrieval episodes Great control over the age and content of retrieved memories Retrieval accuracy can be assessed	Cannot be used to investigate remote memories Might interfere with the natural encoding of autobiographical memories

in the hippocampus [28], possibly reflecting the influence of the amygdala on memory retrieval [29]. This idea was supported by an fMRI study that found greater amygdala–hippocampal interactions for AMs than for semantic memories (Figure 2a) [30]. In this study, amygdala activity was also highly correlated with right ventrolateral PFC regions, suggesting an interaction between emotional content and AM construction. The effects of emotion on amygdalar–hippocampal activations have been linked to enhanced recollection during LM [29], and it is reasonable to assume that this is also true for AM, given that patients who have lesions in the medial temporal lobe (MTL) and the amygdala are more likely to be impaired in retrieving emotional AMs compared with patients who have MTL damage excluding the amygdala lesions [31,32].

Brain activity during AM is modulated not only by the intensity of the emotion (arousal) but also by its positive versus negative quality (valence). In an fMRI study [27], positive (relative to negative) memories activated medial PFC, temporopolar and entorhinal regions, whereas negative (relative to positive) activated a right temporal region. Another study from the same group replicated the medial PFC activation for positive AMs and the right temporal activation for negative AMs [33]. The medial PFC findings are consistent with the results of functional neuroimaging evidence that links medial PFC with reward and appetitive processing [34]. However, medial PFC sometimes responds to negative emotions, which suggests that it is involved in arousal rather than positive valence [35]. A possible solution of these inconsistencies is that distinct subregions of medial PFC are differentially involved in positive valence versus arousal [36].

Turning to vividness, AMs are usually richer in sensory details than LMs. This is not surprising given that AMs are associated with the complex, multisensory 3D environment of the real world, whereas LMs are associated with the impoverished sensory environment of the laboratory. Accordingly, compared with LM, AM was found to elicit greater activity in regions that have previously been associated with visuospatial imagery, such as cuneus and parahippocampal regions [3]. Consistent with these findings, generating images from AM (e.g. imagining an AM involving a car), compared with semantic memory (e.g. imagining a specific car model), yielded greater activity in cuneus/precuneus (Figure 2b) and parahippocampal regions [37]. Consistent with the role of the precuneus in visual imagery, AM studies have found correlations between activity in this region and ratings of vividness [38]. Occipital and cuneus/

precuneus activations might also underlie a late posterior component observed in an electrophysiological study that investigated the time course of brain activity during AM retrieval [39]. The late time course of visual cortex activity has been confirmed by an fMRI study that showed that, whereas hippocampal activity related to memory access occurs early, visual cortex activity related to elaborating and re-experiencing memory occurs late (Figure 2c) [40]. Finally, complementing these neuroimaging findings, patients who have visual cortex damage have distinct retrograde AM deficits [41].

Given that emotion and vividness contribute to AMs, an interesting question is whether their contributions occur simultaneously or at different points during AM retrieval. Even if emotion and vividness ratings are positively correlated in behavioral studies [42], the time course of the underlying processes might be different. This is the conclusion of a recent fMRI study in which participants retrieved AMs through generic cues (Box 1) and then rated each on emotion and reliving [40]. Participants indicated when a specific AM was found (average 12 s) and then continued elaborating the memory (24 s post cue). Whereas emotion ratings were correlated with early amygdala activity, reliving ratings were correlated with late occipital activity. This finding indicates that emotion contributes to AM retrieval even before event-specific memories are completely formed, whereas vividness develops late, as reflexive processes turn to recovered visual images.

In sum, functional neuroimaging studies of AM have associated emotional processing mainly with the amygdala, and vividness with occipital and cuneus/precuneus activity. Although functional neuroimaging evidence is missing, AMs that involve strong auditory, tactile or taste sensations should also involve activity in the corresponding sensory regions. Emotion and vividness have also been associated with increased activity in the hippocampus, which is consistent with the strong link between hippocampal activity and recollection established in LM [43]. However, these studies cannot determine whether the role of the hippocampus in recollection is limited to recent memories or applies also to remote memories. To address this issue, which has important implications for models of consolidation, functional neuroimaging studies must turn to AM.

The remoteness of autobiographical memory: implications for memory-consolidation models

One of the main strengths of functional neuroimaging of AM is that it enables the study of the neural correlates of remote memories, which cannot be created in the laboratory, and recent memories, which is a crucial issue for current models of memory consolidation. According to the standard consolidation model (SCM), the hippocampus has a time-limited role in the storage and retrieval of AMs, whereby memories become independent from the hippocampus and dependent upon neocortical areas following consolidation [44]. By contrast, the multiple trace theory (MTT) posits a permanent role for the hippocampus in the retrieval of memories that are detailed and vivid [45]. These issues continue to be strongly debated [46] and functional neuroimaging studies of AM provide the opportunity to examine them in healthy individuals. SCM predicts greater hippocampal activity for recent than for remote AMs (i.e. a remoteness effect), whereas MTT predicts that, if both types of AMs are equally detailed and vivid, they should elicit similar hippocampal activity (i.e. no remoteness effect).

Box 2. Autobiographical memory and the episodic–semantic distinction

Episodic memory refers to remembering unique past events together with their associated contextual details and involves autonoetic consciousness, the capacity for mental time travel [63]. By contrast, semantic memory refers to knowing facts about the world and about our life that is associated with noetic consciousness [63]. Autobiographical memories (AMs) are an integration of episodic and semantic contents. For example, the AM of a birthday party might include a vivid image of the cake and the people singing around the table (episodic memory) intermixed with knowledge about the date of the birthday and the standard sequence of events (script) of a birthday party (semantic memory). The proportion of episodic and semantic components within AMs depends on several factors, including the following:

(i) The age of memories. AM tests cover a large area, extending from the domain of episodic tests to the domain of semantic tests (Figure Ia, see next page). Recent AMs tend to be more episodic (rich, contextual details), whereas remote AMs tend to be more semantic (abstract and schematic).

(ii) Event frequency. Unique events tend to be more episodic and repeated events tend to be more semantic (Figure Ib).

(iii) Rehearsal. Infrequently retrieved memories tend to be more episodic and repeatedly retrieved memories tend to be more semantic.

(iv) Age and mental health of participants. Older adults [64,65] and some patient populations, such as depressed patients [66], tend to remember fewer episodic details than healthy young adults.

Functional neuroimaging studies have investigated the contribution of episodic and semantic components in AM by contrasting AM with autobiographical facts or personal semantic memory (e.g. birthday date), or repeated AMs (e.g. washing the dishes) [28,61,67,68]. For example, using a prospective method (Box 1), Levine *et al.* asked participants to carry a tape recorder and record brief descriptions of unique AMs and repeated AMs, which were later played to them in the scanner [67]. Unique AMs were associated with greater activity in medial prefrontal cortex (PFC), medial temporal lobes (MTL), posterior cingulate and other brain regions, indicating a greater degree of self-referential processing and spatial imagery compared with repeated AMs. Similarly, Addis and collaborators found that unique AMs relied on left precuneus and posterior cingulate regions involved in spatial imagery, but both unique and repeated AMs engaged medial PFC, reflecting greater self-referential processing in these AM tasks compared with a semantic control task [28,68].

The different proportions of episodic and semantic components depend upon the specificity of the AM (Figure Ib). Episodic and semantic contents in AM dynamically interact during memory construction [8]. Consistent with this idea, the lateral temporal gyrus, a region that is active in laboratory memory (LM) during semantic memory retrieval [69], is typically active during AM retrieval [4], and bilateral activity in this region might reflect greater specificity [11], with right hemispheric damage having a greater impact on AM [70]. Moreover, activation related to repeated AMs comes online earlier than unique AMs [68] and longer retrieval times lead to a more specific AM [11], which suggests that repeated AMs are the preferred level of access and that additional construction processes are required to access specific events.

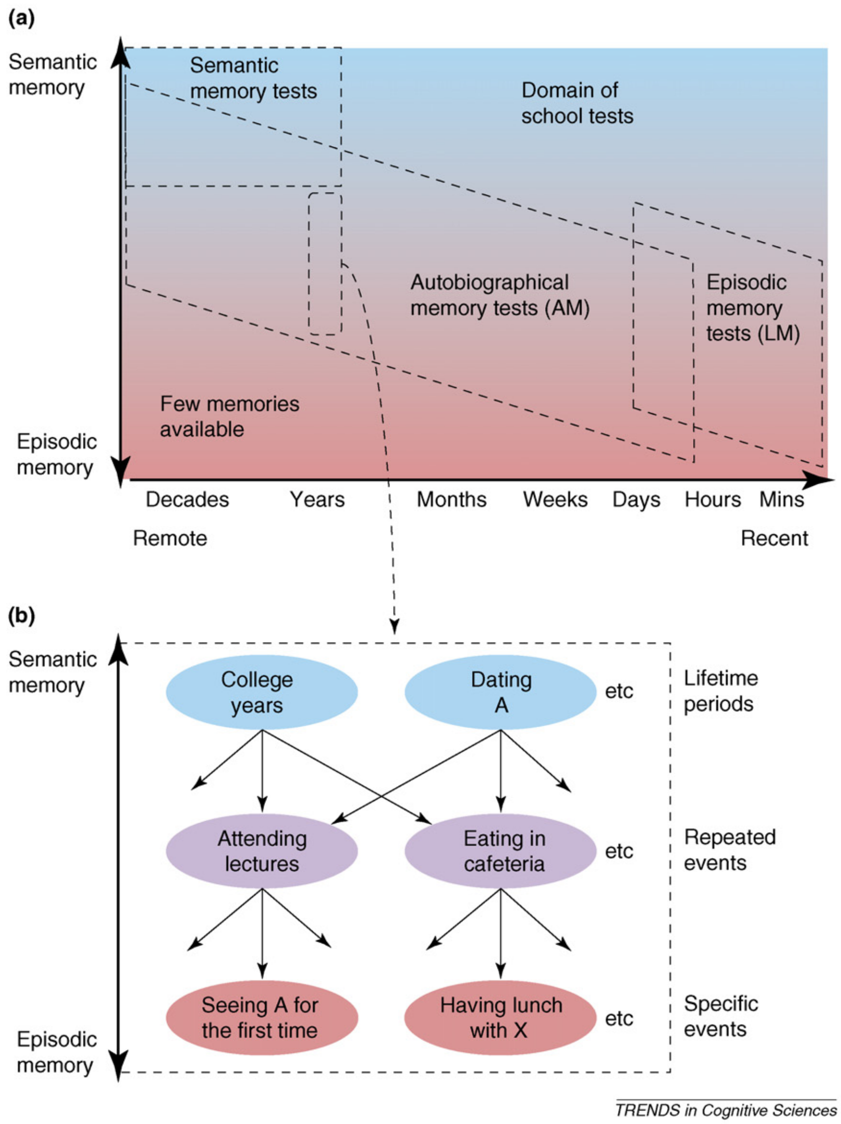

Figure I. (Box 2) Organization of autobiographical memory. **(a)** If one assumes a continuum from the purest episodic memories to the purest semantic memories and plots this continuum against the age of memories, from minutes to decades, different kinds of memory tests can be described as covering different areas of the resulting space. Episodic memory tests (i.e. LM) measure recent memories that are mainly episodic, and semantic memory tests (e.g. factual knowledge tasks) measure remote memories that are mainly semantic. Recent semantic memories are measured by scholastic tests, whereas remote memories that are largely episodic are rare. **(b)** AMs are organized in a hierarchical, nested structure, ranging from more semantic (general) to more episodic (specific) and including lifetime periods, which represent general knowledge characteristics of an extended duration of time, repeated events, involving generic episodes that represent the preferred level of access to AM, and specific events, which are unique episodic memories. Thus, the retrieval of an AM can encompass a more general or specific event.

Although a few functional neuroimaging studies have found the remoteness effect that is predicted by SCM [27,47], most of the studies that compare remote and recent AMs have not, supporting MTT (Figure 3) [2,26,28,38,48–52] and consistent with emerging evidence in the patient literature that suggests that MTL damage can impact remote AMs greater than was previously found [53]. However, neuroimaging evidence cannot irrefutably determine the necessity of the hippocampus in the retrieval of remote AMs. Furthermore, the interpretation of functional neuroimaging evidence that supports MTT is complicated by several factors that modulate hippocampal activity during AM, including the following:

(i) Re-encoding of AMs. Hippocampal activity can reflect re-encoding processes that occur during retrieval [54]. Yet, consistent with MTT, a study that used self versus other photographs as retrieval cues found greater left hippocampal activity during AM retrieval for recent and remote events when compared with viewing novel 'other' photographs [38]. Further research is needed to determine whether these results persist when controlling for encoding success on novel items.

(ii) Vividness and detail of AMs. MTT predicts similar hippocampal activity for remote and recent AMs only if these two kinds of AMs are matched in vividness and detail. Supporting the importance of this condition, in a study that found a remoteness effect in the hippocampus, the effect disappeared when potential confounding factors, including detail, were entered as covariates in fMRI analyses [28].

(iii) Method used to elicit AMs. In the pre-scan interview method, participants might recall the interview rather than the original event, dramatically reducing

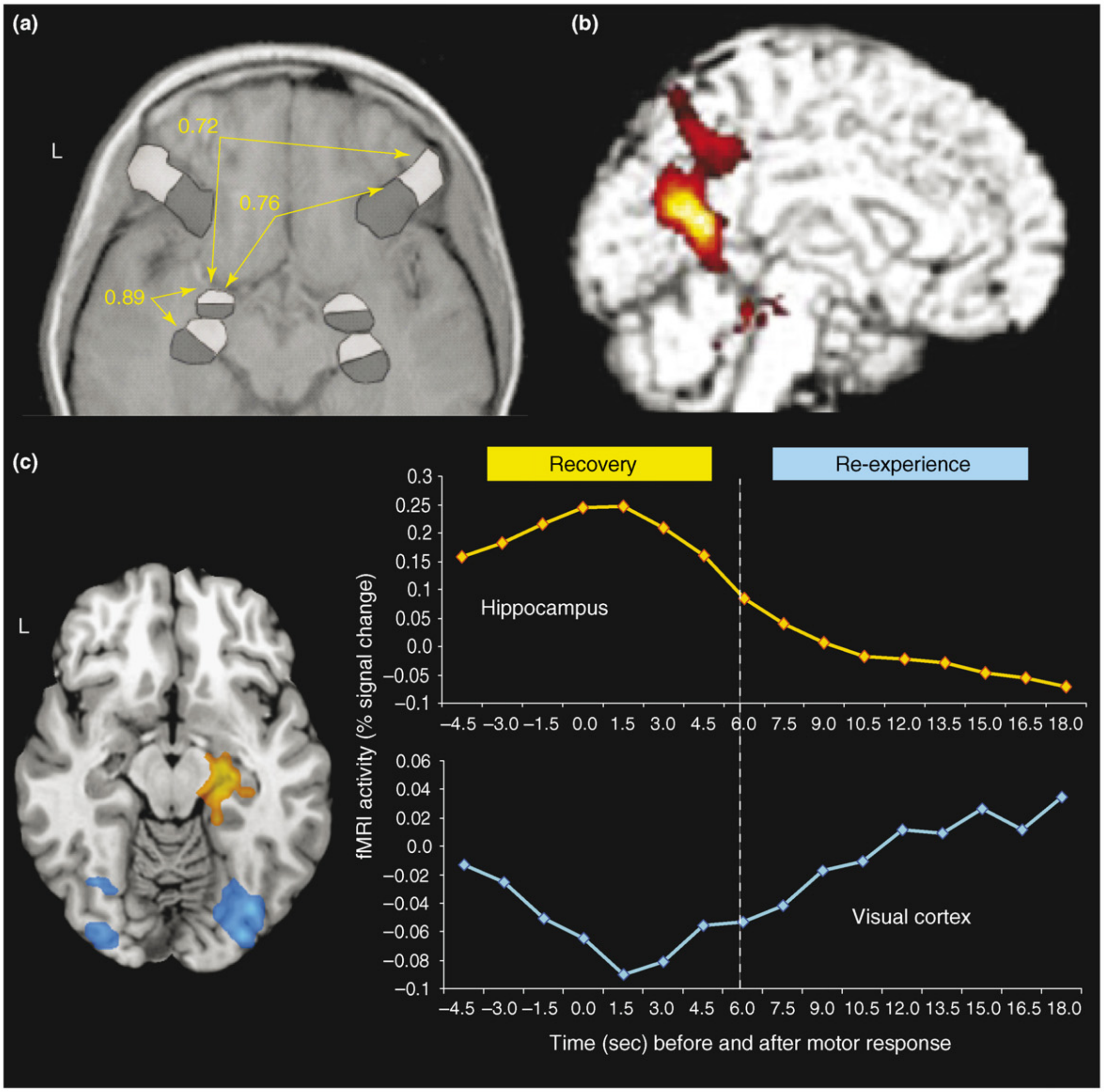

Figure 2. Amygdala and visual cortex regions involved in emotion and recollection during AM retrieval. **(a)** Co-activation of amygdala, hippocampus and right ventrolateral cortices found during the retrieval of AMs compared with semantic memories [30]. Reprinted from Ref. [30] with permission from Elsevier, © 2005. **(b)** Activity in cuneus/precuneus and parahippocampal regions was greater when generating images from AM than from semantic memory [37]. Reprinted from Ref. [37] with permission from Elsevier, © 2006. **(c)** Activity in the hippocampus related to memory access occurs early, whereas visual cortex activity related to elaborating and re-experiencing memory occurs late [40]. Adapted, with permission, from Ref. [19].

the age of memories retrieved in the scanner. This could explain why some studies that used this method failed to find a remoteness effect [2,48]. Yet, consistent with MTT, a remoteness effect has been missing in studies that used other methods [7,38,49,50].

(iv) Amount of time allowed for AM retrieval. It has been suggested [38,51] that shorter retrieval times enable the retrieval of details for recent but not for remote memories, leading to a remoteness effect [26], whereas longer retrieval times enable the retrieval of details for both kinds of memories, reducing or eliminating the remoteness effect [51].

(v) How remote are 'remote memories'? Memories labeled as 'remote' in functional neuroimaging studies have been as recent as two years [50] and as old as 30 years [51]. This variability reflects a lack of specificity in theories of memory consolidation. In fact, functional neuroimaging studies of LM have looked for consolidation-related changes in hippocampal activity during intervals that would normally be classified as 'recent' in AM studies, such as one week [55].

(vi) Lifetime period of remote memories. There is considerable behavioral evidence that AMs from adolescence and early adulthood are remembered better than AMs from other time periods, a phenomenon known as the reminiscence bump [56]. Thus, the quality of remote AMs and their associated hippocampal activity might vary depending on when they are sampled.

(vii) Age of the participants. Investigating the neural correlates of truly remote AMs requires scanning older participants, but aging itself can lead to a reduction in hippocampal activity [57]. Also, there is evidence of hemispheric asymmetries in the remote-

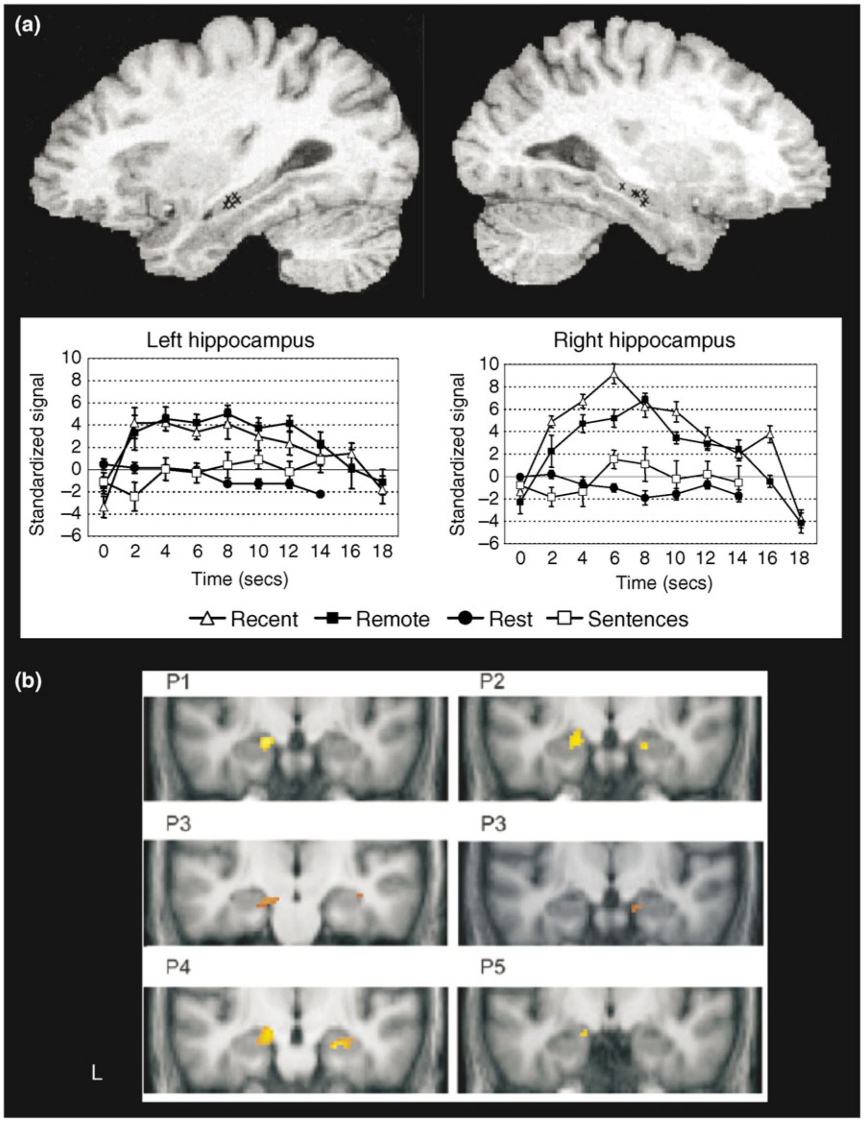

Figure 3. Support for the multiple trace theory (MTT) is suggested by evidence for hippocampal involvement in both recent and remote time periods during AM retrieval. **(a)** An example of equivalent activity in the hippocampus for both recent and remote AMs, which did not differ on ratings of vividness, emotional intensity, importance or the number of details [51]. Mean activity in right and left hippocampi for recent AMs (<4 years old), remote AMs (>20 years), a sentence completion task and rest. Center of activation per individual is indicated (X). Reprinted, with permission, from Ref. [51]. **(b)** Hippocampal activity, following small volume correction, for AMs from recent to remote time periods [52]. P1 = 0–17 years; P2 = 18–30 years; P3 = >31 years, except for the past 5 years; P4 = past 5 years, except the past 12 months; P5 = past 12 months. Reprinted from Ref. [52], with permission from Oxford University Press.

ness effect [26,52], and aging is known to reduce hemispheric asymmetries in brain activity [58]. In fact, fMRI studies have found activity in the left hippocampus in young adults, whereas bilateral activity has been found in older adults for some remote periods [52,59], but the effects of remoteness and age have not been disentangled.

Although the hippocampus has been the focus of most functional neuroimaging studies, other brain regions are also sensitive to the age of memories. The most consistent finding is greater activation in the retrosplenial cortex for recent compared with remote AMs [7,27,38,50]. Several accounts have been suggested for the role of the retrosplenial cortex in recent AMs, including the construction of generic visual representations, retrieval of personally familiar information, emotional processing and vivid recollection. PFC regions were also found to be sensitive to the age of AMs, but results have been more variable, with some studies showing greater PFC activity for recent AMs [48,49] and other studies showing greater PFC activity for remote AMs [7]. Moreover, there is evidence that different PFC regions are activated depending on the age of the AMs [47,50].

Concluding remarks

Functional neuroimaging studies of AM can help to clarify the network of components that orchestrate the recovery and conscious experience of our personal past. Following a retrieval cue, memory search processes, which are mediated by left lateral PFC and interact with self-referential processes via medial PFC, lead to retrieval of a spatiotemporally specific event. Recollection, which is mediated by the hippocampus and the retrosplenial cortex, is enhanced by emotional processing in the amygdala and

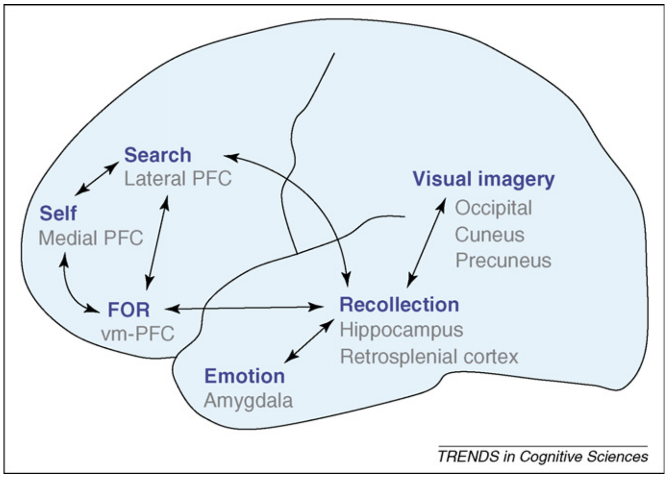

Figure 4. A simplistic description of the most crucial components of the AM retrieval network: (i) search and controlled processes, involving left lateral prefrontal cortex; (ii) self-referential processes, in medial PFC; (iii) recollection, involving the hippocampus and the retrosplenial cortex; (iv) emotional processing, in the amygdala; (v) visual imagery, in occipital and cuneus/precuneus regions; and (vi) feeling-of-rightness (FOR) monitoring via ventromedial PFC (vm-PFC) regions.

visual imagery in occipital and cuneus/precuneus regions. Because retrieved AMs might be inappropriate or incorrect, their contents are monitored via FOR in ventromedial PFC. Although several other brain regions are involved, the foregoing regions are the most crucial components of the AM retrieval network (Figure 4). Current studies have established that functional neuroimaging can answer important questions regarding the construction, phenomenological qualities and temporal dimensions of AM. The challenge for future studies will be to develop new techniques for examining AMs in the scanner that can answer multifaceted questions concerning where these components interact (Box 3).

Box 3. Questions for future research

- The protracted retrieval process that is involved in the construction of AMs is poorly understood. How are participants able to sift through events across their lifespan to select particular instances? AMs are frequently used to inform or entertain; how do these social functions change the neural correlates that underlie construction?
- Construction is just one of the many ways in which AMs are remembered in the real world. Developing new techniques to elicit other types of AMs (e.g. involuntary memories) in the scanning environment would provide greater flexibility and the opportunity to ask novel questions using functional neuroimaging.
- Self-referential processing is a defining aspect of AMs, closely related to the emotional meaning attached to our memories. What is the relationship between AM activations in medial PFC associated with emotional processing and those associated with self-referential processing? Do these processes interact? Are different medial PFC subregions involved?
- How can functional neuroimaging studies of AM disentangle the neural correlates of AM that change with the age of the participant and/or the life period from which AMs are sampled (i.e. reminiscence bump)?
- What are the contributions of subregions within the MTL and the contributions of brain regions, apart from the hippocampus, to the age of the AM?
- Typically, participants select and date AMs outside the scanner, but how can we judge when our AMs occurred? What are the neural correlates of the temporal judgment of AMs?
- How do the neural correlates of AM differ with respect to gender?
- The interpretation of functional neuroimaging studies of AM is often complicated owing to several methodological considerations. How can neuropsychological evidence and functional neuroimaging in these populations inform our investigations of the functional neuroimaging of AM?

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