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Contributions of Episodic Memory to Imagining the Future

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Introduction

Most of our thoughts involve consideration of things we have experienced and what we plan to do in the future. We constantly ruminate over the events in our lives, "replaying" them in our minds, analyzing their consequences, imagining new endings, and predicting what will happen in the future. The extent to which this happens tells us how important it is to our survival; it emphasizes that a primary function of the brain is to consider the outcome of what has happened before and use this information to determine future behavior. In this sense, remembering the past and imagining the future are functionally linked.

Recent research has given insight into the relation between remembering and imagining. *Episodic memory*, or memory of events for which the specific time and context are recalled (Tulving, 1972), has been studied in great detail. However, it is only in the last few decades that the similarities between episodic remembering and imagining have been explored in depth. Initial evidence for this link came from studies of patients with damage to brain regions such as the medial temporal lobe and prefrontal cortex (Hassabis *et al.*, 2007; Tulving, 1985; Wheeler, Stuss, and Tulving, 1997). These patients suffered from amnesia and could not remember events from their past, but more surprising was the difficulty they had when asked to imagine their future. These findings suggested that memory and imagination both rely on the ability to mentally project oneself into representations of scenarios outside the present. Neuroimaging research has confirmed this idea, demonstrating that both remembering and imagining activate a common core network that had previously been associated with autobiographical memory retrieval (for a review, see Chapter 13), including the prefrontal cortex, medial temporal lobe, and posterior parietal cortex (Addis, Wong, and Schacter, 2007; Okuda *et al.*, 2003; Schacter, Addis, and Buckner, 2007, 2008; Schacter *et al.*, 2012; Szpunar, Watson, and McDermott, 2007). This network, which is now thought to comprise part of the "default network" due to its activation during rest, is involved in numerous forms of self-projection, including autobiographical memory, imagining the future, and imagining the perspectives of other people (Andrews-Hanna, 2011; Buckner, Andrews-Hanna, and Schacter, 2008).

The Wiley Handbook on the Cognitive Neuroscience of Memory, First Edition.
Edited by Donna Rose Addis, Morgan Barense, and Audrey Duarte.

Episodic Memory as a Constructive Process

The concept of episodic memory was first described by Endel Tulving (1972). He argued that semantic memory, or general conceptual knowledge not tied to any specific event, exists in contrast with another class of memory: recollection of specific episodes with identifiable spatial and temporal contexts. It is this latter sort of memory that is involved when people remember what it was like to experience things that have happened in their past, such as attending a graduation or wedding, and it is also thought of as being the type required when participants are exposed to various stimuli (e.g., lists of words) and then asked to recall them (though see Gilboa, 2004; McDermott, Szpunar, and Christ, 2009, for a discussion of the neural distinctions between these two types of events). What is common to both of these cases is that during recall, the original episode is to some extent mentally reinstated along with features of its setting. Tulving termed this *episodic memory*, and while he acknowledged that episodic and semantic memory work together, he believed that they could also function independently to a degree that made the distinction one worth considering. Furthermore, he later suggested that episodic memory requires a special sort of consciousness, termed "autonoetic consciousness," which allows a person to have knowledge of the timeline of his or her own life, and the understanding that each event that has been experienced is tied to a "self" whose existence is constant across time (Tulving, 1985). Autonoetic consciousness was thus argued to be necessary for projecting oneself back into specific moments in the past, and therefore for the remembrance of an episodic memory.

Episodic memories can be inaccurate or distorted, which is to say that they tend not to be exact renditions of how the events actually occurred at the time. They may be more like summaries of events that capture the general idea of what happened, often with very vivid perceptual details but with no guarantee of their accuracy (see Chapter 8 for more discussion of memory distortion). Some have proposed that memory distortions result from the *reconstructive* nature of episodic memory: when we recall an episodic memory, we piece together fragments of a scenario and recombine them to form the event (Barclay, 1986; Bartlett, 1932; Neisser, 1986; Schacter, Norman, and Koutstaal, 1998). This form of recall is thought to occur because when an event is experienced, its various elements and features are processed in topographically separate brain regions and this creates a pattern of activity that is distributed across the entire brain. During recall, it is therefore necessary to at least partially restore this pattern, often via the encounter of a cue or fragment of the memory that allows the brain to "complete" the rest of the pattern (Schacter, Norman, and Koutstaal, 1998).

Memory and Imagination

It has been suggested that the reconstructive nature of memory provides it with a great deal of flexibility (Schacter and Addis, 2007). Bartlett (1932) noticed early on that our ability to form brief mental images allows us flexible use of our memories:

> By the aid of the image … a man can take out of its setting something that happened a year ago, reinstate it with much if not all of its individuality unimpaired, combine it with something that happened yesterday, and use them both to help him solve a problem with which he is confronted today. (p. 219)

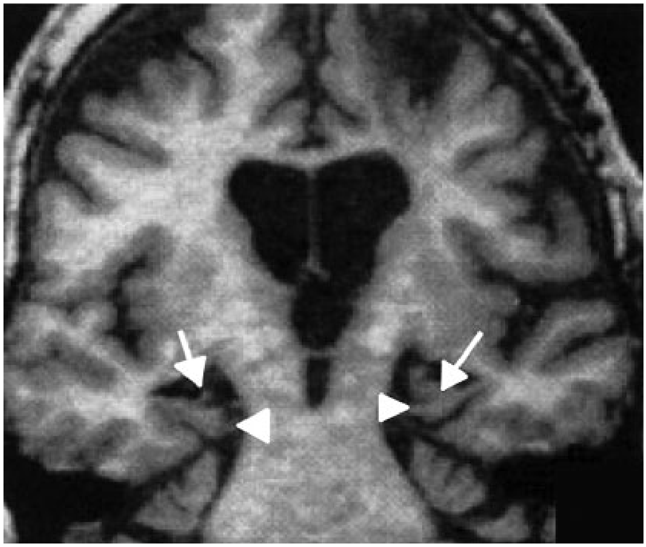

Figure 14.1 Magnetic resonance image showing patient K.C.'s severe atrophy of the right and left hippocampus (arrows) and parahippocampal gyri (arrowheads). Adapted from Rosenbaum *et al.* (2000).

The flexibility of our episodic memory system enables us to take details from our past experiences and voluntarily alter or rearrange them to form representations of events that have not yet happened to us (Schacter and Addis, 2007). In other words, our ability to imagine things that might occur in the future is dependent on our capacity to remember the past. When the concept of episodic memory was first developed, its focus was on the domain of remembering past experiences (Tulving, 1972). However, the episodic system has now been reconceptualized as a broader mechanism for simulation of events, with which we can voluntarily re- or pre-experience events in rich detail, and in both the past and the future.

The amnesic patient K.C. (Figure 14.1) is one of the early cases that contributed to this idea (Tulving, 1985). After suffering a head injury in a motorcycle accident, he could not recall a single specific event from his past, and more interestingly described experiencing mental "blankness" when trying to imagine what he might be doing in the future. Despite these deficits, K.C.'s personal semantic memory and general knowledge of the world was intact (Rosenbaum *et al.*, 2005). Observations of this patient prompted Tulving to suggest that the ability to remember episodes from the past is vital for imagining the future. A decade later, it was noted that patients with memory loss following damage to the prefrontal cortex also exhibited a lack of self-concern, limited plans and ambitions for the future, and a reduced desire to daydream and self-reflect (Wheeler, Stuss, and Tulving, 1997). Since these patients also typically retained their semantic knowledge, this finding offered even more support for the idea that in the absence of recollective episodic memory, the ability to mentally travel forward in time is impaired.

Amnesic patient D.B. was reported to show a similar pattern of parallel deficits following cardiac arrest and hypoxic brain damage (Klein, Loftus, and Kihlstrom, 2002).

D.B. showed profound impairment on episodic memory tasks, but his semantic knowledge was mostly spared. Interestingly, on specific measures of temporal awareness, he was unable to provide details about events in his own personal past or future, but he possessed adequate semantic knowledge of both past and future events in the public domain. In concordance with Wheeler, Stuss, and Tulving's (1997) arguments, this suggests that self-referential, episodic mental time travel can be dissociated from semantic awareness of general temporal knowledge. Moreover, it suggests that *episodic* memory plays a particularly important role in imagining future *episodes*, but that semantic memory is sufficient to support semantic forms of future thinking (Atance and O'Neill, 2001).

New findings from patients with semantic dementia illustrate, however, that episodic future thinking requires the contribution of both episodic and semantic elements (for a review, see Chapter 20). Semantic dementia patients have anterior temporal lobe damage and corresponding semantic memory deficits, but intact episodic memory (Hodges *et al.*, 1992). Such patients have been shown to recall events from their past in as much detail as controls, but are specifically impaired at imagining detailed future events (Irish *et al.*, 2012). This finding indicates that while access to memories of past events is necessary for episodic future thinking, it is also necessary to draw upon conceptual knowledge when constructing and imagining a new future event, perhaps using this information as an organizational framework in which to place the episodic details. In support of this idea, it has been shown that when participants construct future events, they draw first upon general personal knowledge before accessing specific episodic details from remembered past events (D'Argembeau and Mathy, 2011). Furthermore, imagined episodic future events, particularly those in the distant future, are clustered into broader future event sequences that are often organized around semantic knowledge about personal goals (D'Argembeau and Demblon, 2012).

Other evidence from amnesic patients has specifically implicated the medial temporal lobes in the ability to imagine the future (Hassabis *et al.*, 2007). Five patients with damage restricted to the bilateral hippocampus were asked to imagine future scenarios in response to a verbal cue. Compared to controls, the descriptions of the imagined events generated by the patients were lacking in richness and spatial coherence. Specifically, the details that they did manage to provide seemed fragmented and incompletely bound together. It was thus argued that the hippocampus also has a significant role in imagining the future, particularly in binding details together and integrating them into a spatial context.

A variety of other studies have illustrated the close relationship between past and future thought. The developmental trajectories of episodic memory and future thinking are similar, with both emerging gradually at approximately four years of age (Atance and O'Neill, 2005; Suddendorf and Corballis, 1997). This emergence corresponds with the ability of children to imagine themselves taking different perspectives (Russell, Alexis, and Clayton, 2010). When children are asked to imagine future scenarios and select one of three items that will help them in those scenarios, it is only by five years of age that they are not distracted by items that are semantically related to the scenario but in fact unhelpful to them (Atance and Meltzoff, 2005). The ability to accurately describe plans for the next day increases significantly between the ages of three and five years (Busby and Suddendorf, 2005), and when children are asked what they did yesterday and what they will do tomorrow, the ability to answer the former question predicts the ability to answer the latter (Suddendorf, 2010). This link between the development of memory and imagination further supports the idea of similar underlying processes.

At the other end of the lifespan, a corresponding deterioration is observed for both abilities. Older adults tend to produce significantly fewer episodic details than younger adults both when remembering past events and when imagining future ones, and the number of details generated for past events is significantly correlated with the number of details generated for future ones (Addis, Wong, and Schacter, 2008; Addis *et al.*, 2010). Such parallel declines in past and future are evident when cued with words, and also when asked to imagine events using pictorial cues (Gaesser *et al.*, 2011). Instead of being able to describe vivid visuospatial aspects of the scenes they imagine, older adults are instead more likely to provide semantic or conceptual information that may or may not be relevant to their imagined events. Furthermore, the number of episodic details generated by older adults is highly associated with their scores on a test of relational memory, which, given the role of the hippocampus in relational memory (Konkel and Cohen, 2009), again points to the importance of the medial temporal lobes for imagining the future (Addis, Wong, and Schacter, 2008). When constructing imagined future events, older adults do not show the same level of activity as younger adults in regions known to be important for vivid episodic detail, such as the hippocampus, parahippocampal gyrus, and precuneus (Addis, Roberts, and Schacter, 2011). In contrast, while elaborating on their imagined events, older adults show greater activation than young adults in lateral temporal areas associated with semantic processing (Figure 14.2). When participants rate how much detail they

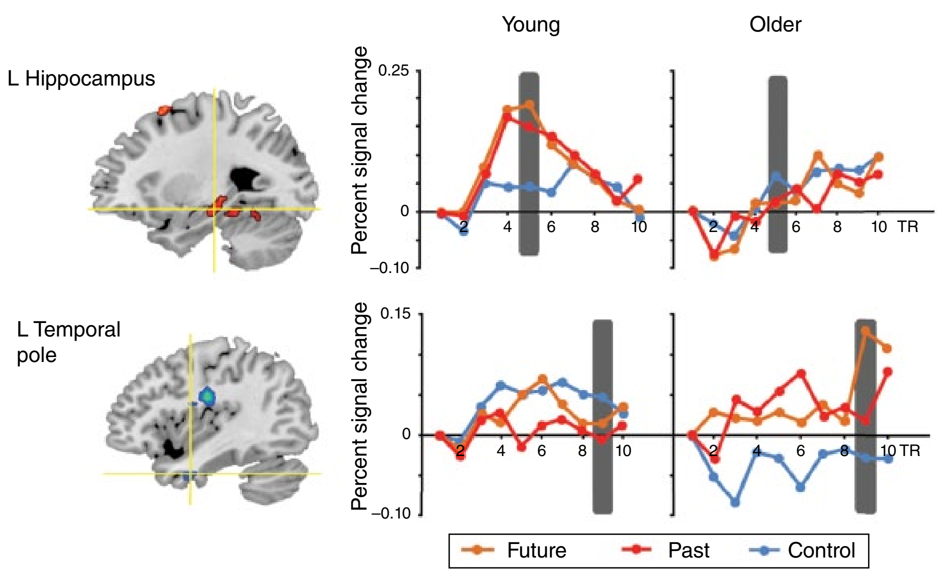

Figure 14.2 Percent signal change extracted from regions more active for autobiographical tasks than the control task in young adults, from Addis, Roberts, and Schacter (2011). Young adults engage the left hippocampus more for both future and past events than for the control task, while this effect is not seen in older adults. Conversely, older adults show more activation in the left temporal pole for the autobiographical tasks than for the control task, an effect which is not observed in young adults.

have generated in their imagined events, the detail ratings of young adults are linearly associated with hippocampal activity, while in older adults the ratings correlate with activity in the lateral temporal lobes (Addis, Roberts, and Schacter, 2011). The tendency for older adults to focus on semantic information instead of episodic detail is therefore not only a behavioral phenomenon, but is also reflected in the neural activity underlying older adults' imagined events.

Electrophysiological and neuroimaging studies have investigated the neural networks involved in both remembering the past and imagining the future, and the finding of a common neural network underlying both processes supports the earlier patient data suggesting a relation between them. Electroencephalography (EEG) evidence shows similar significant left frontal activation for the construction of both remembered and imagined events (Conway *et al.*, 2003). PET and fMRI studies have indicated that both remembering and imagining tend to produce similar activation in a core network of regions, including medial prefrontal, medial temporal, and posterior parietal cortices (Addis, Wong, and Schacter, 2007; Hassabis, Kumaran, and Maguire, 2007; Okuda *et al.*, 2003); the widespread nature of this network illustrates the diverse sensory, perceptual, spatiotemporal, and emotional components of these representations. Common network activation points to a similar underlying cognitive process, potentially that mental images acquired in the past and stored in posterior areas are then being reactivated during both remembering and imagining via direction from prefrontal regions (Szpunar, Watson, and McDermott, 2007).

These active regions comprise part of what we now refer to as the *default mode network* (Buckner, Andrews-Hanna, and Schacter, 2008; Raichle *et al.*, 2001), a term derived from the fact that this extensive network is notably active when participants are allowed to mind-wander and are not engaged in an external stimulus-driven task. Meta-analyses have now enabled the parcellation of the default network into subsystems (Andrews-Hanna, 2011; Buckner, Andrews-Hanna, and Schacter, 2008; Kim, 2012): (1) the medial temporal lobe subsystem, supporting memory-related processes including the recall and simulation of episodic events, and consisting of the hippocampus, parahippocampal gyrus, retrosplenial cortex, and ventromedial prefrontal cortex (PFC); as well as (2) the dorsal medial PFC subsystem, supporting inferences about the mental states of the self and others, and consisting of the dorsal medial PFC, temporoparietal junction, lateral temporal cortex, and temporal pole (Andrews-Hanna, 2011). The subsystems both converge on the posterior cingulate cortex and the anterior medial PFC; these two regions serve as hubs linking the subsystems together. Accordingly, the shared neural substrate of remembering and imagining draws on many of these subsystems and hubs.

As a result of the converging evidence linking remembering and imagining, Schacter and Addis formulated their *constructive episodic simulation* hypothesis, which suggests that in order to simulate hypothetical situations, the episodic memory system extracts specific details from past experiences and recombines them in a coherent way (Addis and Schacter, 2012; Schacter and Addis, 2007). This theory fits well with the idea of episodic memory for the past being highly constructive in nature (Bartlett, 1932; Neisser, 1986; Schacter, Norman, and Koutstaal, 1998), with events encoded in a piecemeal fashion instead of as a fixed "instant-replay" style recording. A constructive system is an economical one, as specific details need not be represented in the brain as many times as the person experiences them. The ability to draw on these details in a novel way to imagine future experiences may be simply an adaptive extension of the inherent system design, such that the outcomes of past experiences can flexibly inform choices made about upcoming events.

An alternative hypothesis for the commonality underlying remembering and imagining was proposed by Hassabis and Maguire (2007). They argue that both of these abilities involve the construction of three-dimensional spatial scenes, requiring the mental representation of a location's spatial layout and the insertion of various event elements at various places within it. This *scene construction* hypothesis was based on the known role of the hippocampus in spatial navigation (Maguire *et al.*, 2000), as well as on their findings that patients with hippocampal damage imagine events that are significantly less spatially coherent than the events of normal controls (Hassabis *et al.*, 2007). Their evidence suggests that the role of the hippocampus in imagining the future is in spatially binding the elements of the event into the scene.

The scene construction hypothesis does not necessarily conflict with the constructive episodic simulation hypothesis, as both theories propose that some form of construction is required in remembering and imagining. Rather, it is likely that both theories are correct and complementary, in that episodic details (e.g., people, locations, and objects) are extracted from previous experiences and then re-bound (and in the case of future events, rearranged) into new three-dimensional scenes. Spatial and contextual information therefore provides a vital platform upon which to build these scenarios. It has been found that the familiarity of a simulated event's location determines how vividly and clearly it will be imagined (Arnold, McDermott, and Szpunar, 2011; Szpunar and McDermott, 2008), which is consistent with the idea of the context as a fundamental base for episodic simulation. Furthermore, remembering and imagining events that take place in familiar locations both engage posterior parietal regions (e.g., posterior cingulate cortex and parahippocampal gyrus) significantly more than remembering and imagining events in unfamiliar locations (Szpunar, Chan, and McDermott, 2009). The similar engagement of posterior parietal regions during remembering and imagining might therefore reflect the fact that both tasks typically require the retrieval of familiar locations. Finally, the hippocampus, known for spatial processing, is particularly important for the generation of specific imagined future events, as opposed to general or more abstract imagined future events, perhaps also reflecting the precise spatiotemporal context characterizing events that are highly specific (Addis *et al.*, 2011). All of this evidence supports the idea that contextual information serves as a foundation for episodic processes.

Differences Between Remembering and Imagining

Remembering and imagining are, of course, not identical processes. We must have some way of distinguishing between experienced and hypothetical events so that we can accurately guide our behavior based on the realities of our environment. In support of this idea, it has been shown that some of the phenomenal characteristics known to accompany the process of remembering the past are slightly different for simulated future events. For example, memories of actual past experiences tend to have significantly more detailed sensory and perceptual features than imagined future events (D'Argembeau and Van der Linden, 2004; Gamboz, Brandimonte, and de Vito, 2010; Johnson and Raye, 1981) and therefore engage visual regions to a greater degree (Addis *et al.*, 2009; Conway *et al.*, 2003; Weiler, Suchan, and Daum, 2010). Real memories also contain more detailed spatial and temporal contextual information, while imagined events are more schematic (Johnson and Raye, 1981). Moreover, the clarity and sensory detail of memories for imagined events dissipates much more rapidly over time as compared to memories of real events (Suengas and Johnson, 1988).

When participants are asked to imagine future events in laboratory-based settings, they are often instructed to generate highly specific scenarios, and in these cases the imagined future events generally take place in precise spatial and temporal contexts (Addis *et al.*, 2011). However, when spontaneous future thoughts are examined instead (i.e., naturally occurring thoughts of the future that were not prompted by some experimental task), they tend to be less specific and more semantic in nature than spontaneous thoughts of the past (Anderson and Dewhurst, 2009). Therefore, naturalistic future thinking seems to be generally more conceptual and less likely to involve specific and detailed episodic scenarios than both laboratory future tasks and thinking about real past experiences. However, it is also noted that repeated rehearsal of apperceptive aspects of both remembered and imagined events (i.e., dwelling on the thoughts and feelings that one would or did have during the event) results in the two types of events being more easily confused (Suengas and Johnson, 1988). More specifically, with this sort of rehearsal that emphasizes emotional components, the sensory and perceptual detail of real memories becomes more difficult to access, while the emotional and cognitive content of the events increases. Consequently, the characteristics that typically distinguish between real and imagined events become less clear. So while remembering and imagining are distinct in many ways, this distinction can be affected by factors such as rehearsal.

Some key differences between remembering and imagining appear to emerge when the event is first being constructed. Both processes involve two phases: (1) the initial construction of an event and (2) the process of mentally elaborating upon it once constructed (Conway *et al.*, 2003). When recalling a memory of a past experience, participants engage in a search process to locate a memory that fits with the provided cue or search criteria, after which the previously experienced representation can be reactivated. In contrast, when imagining a new future event, depending on the task and cue involved, disparate episodic details from multiple memories must be located and then incorporated into the new scenario. Therefore, imagined future events have elements of generation, recombination, and construction that are more intensive than for remembered past events. In an fMRI study, Addis, Wong, and Schacter (2007) had participants indicate with a button-press once a past or future event had been generated, after which they elaborated on the constructed event in as much detail as possible. During initial construction of these events, there was significant differentiation in active regions between past and future. The ventrolateral prefrontal and right frontopolar cortices were more active during construction of future than past events. Furthermore, while the left hippocampus was recruited for construction in both temporal directions, the right hippocampus showed selective engagement for the construction of future events (Addis, Wong, and Schacter, 2007). In contrast, during elaboration, these differences were no longer present and a common core network of

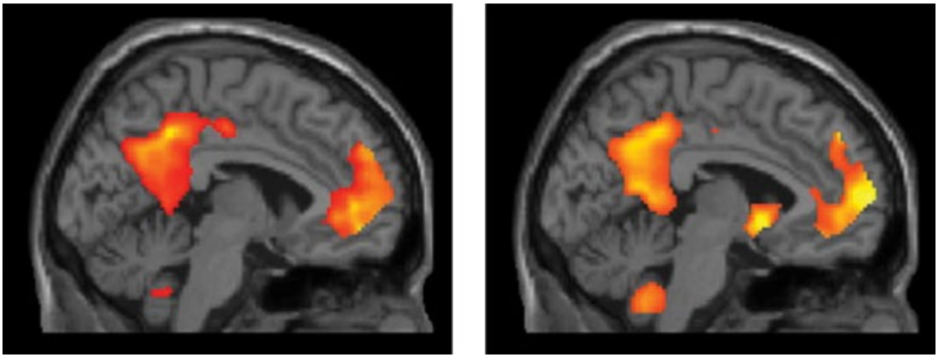

Figure 14.3 An illustration of the striking commonalities in left medial prefrontal and parietal activity during the elaboration of past (left) and future (right) events, relative to a control task. Adapted from Addis, Wong, and Schacter (2007).

activation was observed for both remembering the past and imagining the future, including left medial prefrontal cortex and medial posterior regions (Figure 14.3).

When the results of the above study were reanalyzed with respect to the amount of vivid detail generated for each event, the specific contributions of some of these regions to the imagination of future events were clarified (Addis and Schacter, 2008). It was found that during elaboration of future events, activity in the right frontal pole and anterior hippocampus was directly related to the amount of detail in each event, as rated by the participant. Given that frontopolar activation has previously been found to correlate with the degree of intentional thought comprising an imagined event (Okuda *et al.*, 2003), the frontal pole activity in this study may reflect the increased intentional information that accompanies thinking about detailed future plans. The anterior hippocampal activity may come from the creation of multiple new associations between the details that are incorporated and encoded into a coherent event (Giovanello, Schnyer, and Verfaellie, 2009).

The Hippocampus and Episodic Simulation of the Future

Within the default network's medial temporal lobe (MTL) subsystem, the hippocampus is one of the most fundamental structures for episodic memory. Input to the hippocampus comes from the adjacent perirhinal and parahippocampal cortices, which each integrating information from object- and spatial-related regions in the ventral and dorsal streams, respectively. Given that the hippocampus receives simultaneous input from both of these streams, it is a structure that is anatomically well-placed to integrate visuospatial information even further (Lavenex and Amaral, 2000; Squire, Stark, and Clark, 2004). There has been a strong focus on the role of the hippocampus (particularly its posterior extent) in representing spatial information, which may explain the specific involvement of the hippocampus for episodic memory as opposed to semantic or procedural memory, since a defining characteristic of episodic memory is the successful reinstatement of an event's initial spatiotemporal context. The hippocampus may act as a sort of cognitive map, storing allocentric representations of space (i.e., in a map-based fashion, regardless of the specific position or perspective of the observer) (O'Keefe and Dostrovsky, 1971; O'Keefe and Nadel, 1978), though others believe that hippocampal involvement in spatial processing is simply one instance of this structure's general function in forming cross-modal associations or arbitrary associations between item or event features (Eichenbaum, 2007; see also Squire, Stark, and Clark, 2004).

The broad connectivity of the hippocampus is thought to allow it to capture and index overall whole-brain patterns of activation that are elicited by the perception or mental representation of an event (Lavenex and Amaral, 2000). Reciprocal connections between the hippocampus and widespread neocortical regions allow a "compressed" representation of the event to be stored in the hippocampus in the form of rapid synaptic changes (McClelland, McNaughton, and O'Reilly, 1995). It has been suggested that what we think of as memory recall involves a recapitulation or reactivation of these previously experienced patterns of activity, resulting in the reinstatement of an earlier mental state. The way in which this occurs may be as a type of pattern completion; if part of the previously elicited pattern of activity is re-encountered, activation may then spread within and from the hippocampus to the remaining components, resulting in the mental recreation of a previous episode (McClelland, McNaughton, and O'Reilly, 1995).

Patient and neuroimaging evidence indicates that the hippocampus may play an important role in imagining the future (Addis and Schacter, 2012; Schacter and Addis, 2009), over and above its already well-established role in remembering the past. A role for the hippocampus in imagining new events is unsurprising, given that a core function of the hippocampus is to bind together disparate features of stimuli and form new associations (Eichenbaum, 2001; Eichenbaum *et al.*, 2012), and these processes are fundamental to the representation of new, multifaceted imagined events. Right hippocampal activity is higher for imagined future events that are later remembered in a cued recall test than for those which are later forgotten, suggesting that hippocampal activity reflects the extent to which the details are successfully bound together and stored in memory (Martin *et al.*, 2011). The amount of recombination and binding required to imagine an event depends largely on how similar it is to previous experiences, and it has been shown that imagined events that are unlikely to occur in real life engage the right anterior hippocampus to a greater extent than more probable events (Weiler, Suchan, and Daum, 2009). The importance of this structure for imagining the future also supports Addis and Schacter's *constructive episodic simulation* hypothesis and Hassabis and Maguire's *scene construction* hypothesis, since an integral part of these ideas is that simulation depends on the binding together of details from previously experienced events into new representations of spatial scenes.

Nonetheless, the role of the hippocampus in imagining the future is currently controversial, due to conflicting evidence for and against the ability of hippocampal amnesic patients to imagine future events. Building on the previously discussed findings reported by Hassabis *et al.* (2007) demonstrating scene construction deficits in hippocampal amnesics, some recent findings have illustrated further that amnesic patients are impaired at episodic simulation of the future (Andelman *et al.*, 2010; Kwan *et al.*, 2010; Race, Keane, and Verfaellie, 2011; Zeman *et al.*, 2012), and that this deficit is in the act of constructing specific episodic scenarios, rather than in simply considering outcomes that might happen in the future (Kwan *et al.*, 2011). In contrast, others report that amnesic patients perform as well as controls on episodic simulation tasks (Hurley, Maguire, and Vargha-Khadem, 2011 [though note that this was a developmental amnesic patient]; Squire *et al.*, 2010).

It has been proposed that the timing of hippocampal damage may affect the extent of the patient's deficit in episodic simulation, such that patients who sustained damage in infancy or early childhood may be less impaired as adults than those whose damage was acquired in adulthood. This idea is based on two lines of evidence. First, developmental amnesic patient Jon, who suffered 50% bilateral loss of his hippocampal tissue perinatally, can imagine future events that are as coherent and detailed as those of control participants (Maguire, Vargha-Khadem, and Hassabis, 2010). Jon's ability to imagine future events is attributed to his residual hippocampal tissue, which is active during autobiographical memory retrieval (Maguire, Vargha-Khadem, and Mishkin, 2001) and scene construction (Mullally, Hassabis, and Maguire, 2012). Second, a group of amnesic children with hippocampal damage resulting from neonatal hypoxia and ischemia were also shown to be unimpaired at imagining fictitious experiences (Cooper *et al.*, 2011), although their later recall of these imagined experiences was significantly worse than that of control children. These two sets of findings have been explained either by potentially active residual hippocampal tissue (as confirmed in patient Jon) or by the reliance on a store of accumulated semantic knowledge which may be able to support scene construction (Addis and Schacter, 2012). This theory of the timing of damage does not explain why patient H.C., another developmental amnesic patient, shows deficits in imagining the future (Kwan *et al.*, 2010), although this result is disputed (Hurley, Maguire, and Vargha-Khadem, 2011).

There are several other factors that may explain the conflicting evidence from amnesic patients, including the way in which simulation ability is measured. The various experiments investigating this issue have used a variety of different tasks. For instance, in the adapted Autobiographical Interview (Addis, Wong, and Schacter, 2008; based on Levine *et al.*, 2002), a single generic cue word is provided and the participant has three minutes to describe as much detail about an imagined event as possible. This task has been used to assess the number of episodic and non-episodic details comprising amnesic patients' future events (Squire *et al.*, 2010). In contrast, the scene construction task (Hassabis *et al.*, 2007) involves provision of the general scenario and the participant is required to build upon the pre-constructed scene, at times receiving prompts about visuospatial information (Berryhill *et al.*, 2010; Hurley, Maguire, and Vargha-Khadem, 2011; Mullally, Hassabis, and Maguire, 2012). The memory and temporal experience questionnaire (Klein, Loftus, and Kihlstrom, 2002) has participants answer questions about their known (semantic) and lived (episodic) past and future (Andelman *et al.*, 2010). The importance of the choice of task is made particularly obvious by the conflicting results found in a single patient: H.C. is unimpaired on the scene construction task (Hurley, Maguire, and Vargha-Khadem, 2011), but significantly impaired on the adapted Autobiographical Interview (Kwan *et al.*, 2010).

The task interacts with patient factors, such as the specific aetiology and nature of the brain damage suffered. Squire *et al.* (2010) argue that many of the patients who have been found to have deficits in imagining the future also have damage to a number of extra-hippocampal regions that could explain their impairment. In support of this claim, damage to regions outside the hippocampus has been shown to affect episodic simulation ability. Patients with damage localized to the posterior parietal cortex or to the prefrontal cortex, and with intact hippocampi, imagine fictitious scenarios in much less detail than controls (Berryhill *et al.*, 2010). Furthermore, it has been shown that semantic dementia patients with atrophy of the anterior temporal lobes, who show deficits in semantic memory but with a relative preservation of episodic memory, are selectively impaired when imagining the future and not when remembering the past (Irish *et al.*, 2012). This same pattern of results was also found in two patients with thalamic lesions (Weiler *et al.*, 2011).

Alternatively, deficits in episodic simulation may be explained by broader deficiencies; some amnesic patients, even those with otherwise normal cognitive abilities, may have a general impairment in their capacity to describe their surroundings, even when no mental projection is required and they are simply asked to describe their present situation (Zeman *et al.*, 2012), though others have not found this to be the case (Race, Keane, and Verfaellie, 2011). It has been argued that amnesic patients who are unimpaired at imagining the future are those who do not suffer from complete amnesia; with their relatively preserved remote episodic memory, such patients are able to draw upon a residual store of episodic details and therefore can construct scenarios in the same way as controls (Addis and Schacter, 2012). However, other patients with intact remote episodic memory still show deficits in future thinking (Andelman *et al.*, 2010). It is clear that much further work remains to be done in order to understand the role of the hippocampus in imagining future events.

Functions of Imagining the Future

According to the constructive episodic simulation hypothesis and related perspectives, the ability to draw on episodic details in a novel way to imagine future experiences is a design feature of episodic memory (Schacter and Addis, 2007; Suddendorf and Corballis, 2007). As noted by Schacter (2012), such a feature must be sufficiently beneficial to the organism that it is worth the associated cost in memory errors that can result from occasionally mistakenly combining those elements. Simulating future events therefore ought to serve important functions for an organism, and several lines of research indicate that this is so.

Conway (2009) suggests that the relationship between remembering and imagining reflects their common purpose: to allow us to maintain goals that refer to time periods extending beyond our immediate circumstances. This idea is based on his experiment in which participants describe as many of their own specific memories as possible for each day prior, up to the point of five days before the present, and then imagine specific upcoming future events in the same manner but in the forward direction in time. The number of specific events listed by participants decreases steadily as time progresses either into the past or into the future, and Conway interprets the range of days on which participants could list multiple specific events to reflect a stable *remembering–imagining window*. This window allows a person to have simultaneous awareness of both recent and approaching events, and it supports the idea that the function of our ability to remember and imagine is to keep a constant and current mental representation of our more immediate goals.

Others have also found that the numbers of remembered and imagined events that had taken or would take place near the present is relatively high, and then decreases linearly with time in both the past and future directions (Spreng and Levine, 2006;

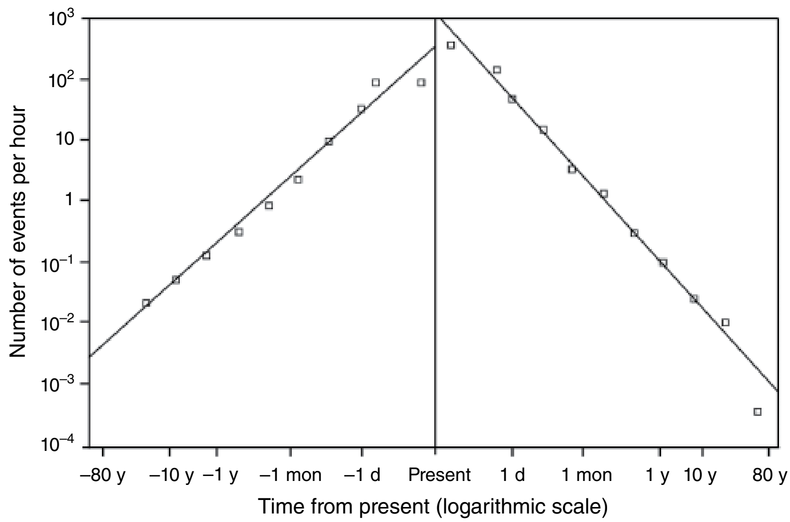

Figure 14.4 The temporal distribution of autobiographical event frequency per hour, plotted as a function of time from the present (days, months, years) into the past and future. Reproduced from Spreng and Levine (2006).

Figure 14.4). In addition, temporally close events are more specific, detailed, and vivid than distant ones (Trope and Liberman, 2003), regardless of whether they are remembered in the past or imagined in the future (D'Argembeau and Van der Linden, 2004), although this may be due to difficulty in imagining a clear location in which to set temporally distant future events (Arnold, McDermott, and Szpunar, 2011). Imagining specific personal goals and the steps required to achieve them engages the same default network regions seen when people imagine future events in general (Gerlach *et al.*, 2011; Spreng *et al.*, 2010). Furthermore, imagined future events that are relevant to participants' personal goals engage medial prefrontal and parietal regions of the default mode network more than imagined events that do not relate to their personal goals (D'Argembeau *et al.*, 2010). When asked to imagine and describe the detailed steps required to solve open-ended problems, patients with temporal lobe epilepsy (and the corresponding episodic memory deficits that accompany medial temporal lobe damage) describe fewer relevant steps than controls (Sheldon, McAndrews, and Moscovitch, 2011), suggesting an association between episodic processes and goal-directed problem solving. These findings converge on the idea that the processes of remembering and imagining serve as a way to inform present behavior while maintaining immediate personal aims.

Mental simulation of the future has other adaptive functions in addition to maintaining personal goals. Imagining specific future events reduces temporal discounting, which is the general tendency to assign relatively less value to a large reward in the distant future than to a smaller reward that could be acquired immediately (Benoit, Gilbert, and Burgess, 2011). In other words, imagining the specific act of receiving the large reward in the distant future reduces the tendency to devalue it. Therefore, imagining future events allows a person to make decisions that he or she may not have otherwise made after simply considering the immediate situation, and these decisions are generally found to be ultimately more beneficial. People often have difficulty following through with their good intentions for the future, frequently because their plans are too vague or they are disproportionately influenced by more immediate goals. Planning in advance the exact actions one will take when faced with a specific situation removes the influence of distracting immediate factors on decision making. Deciding to engage in behavior *X* when in situation *Y*, or forming an "implementation intention" (Gollwitzer, 1999) creates a mental representation of the goal behavior for which recall is triggered by encountering the situation itself. This ease of recall allows the goal-directed behavior to become almost automated and therefore less influenced by distraction. Consequently, the ability to imagine events that might happen in the future allows people to make more advantageous decisions.

At a more basic level, planning for the future has survival value, and the ability to anticipate threats to one's own life was likely a driving evolutionary factor behind the development of a memory system that allows for imagination. Klein, Robertson, and Delton (2010) argue that for this reason, the episodic system is in general even more oriented towards the future than the past, despite the focus of previous research in this area. They suggest that memory performance should therefore be at its optimal level when planning for the future, and especially when considering future scenarios in which survival might be in question. In support of this idea, Klein *et al.* showed that when participants consider an event involving camping in the woods and judge the relevance of a list of items to the situation, framing the event in terms of a specific plan for the future results in better memory for the item details than when participants are asked to think of the items in the context of a previous memory of camping in the woods (Klein, Robertson, and Delton, 2010). Object-location memory is also improved when the encoding context calls survival into question, as participants show better memory for the locations of food and animals when asked to imagine the items in a survival scenario, as opposed to when imagining them in a scavenger hunt or hunting contest (Nairne *et al.*, 2012).

A higher-level cognitive role of episodic memory is in maintaining a stable and healthy sense of self, and this function has now been demonstrated to extend to episodic simulation of the future. The ability to remember past autobiographical events, particularly from early adulthood, seems to be vital for preserving a strong identity (Addis and Tippett, 2004). Highly significant memories that are personally meaningful and described as "self-defining" may be particularly important for maintaining identity and for the development of self-worth (Sutin and Robins, 2005). It has now been shown that people have corresponding self-defining imagined future events as well as remembered past events (e.g., "when I get married," or "when I graduate from university"), and these self-defining future events carry significant personal meaning, create a sense of self-continuity, and contribute to self-esteem (D'Argembeau, Lardi, and Van der Linden, 2012). When people imagine episodic events that will happen in their future, these events tend to cluster around time periods in which participants expect to acquire certain future self-images or self-definitions (e.g., "I will be a parent"), suggesting that these episodic future events are tied to semantic representations of the future self (Rathbone, Conway, and Moulin, 2011). Manipulating participants' perceived self-efficacy alters the way in which they imagine future episodic events; those prompted to identify themselves as having high self-efficacy imagine events that are more specific and that contain more positive words (Brown *et al.*, 2012), further illustrating the mutual influence of episodic future thinking and self-related constructs.

Emotional valence significantly affects episodic processes (for a discussion of the influence of emotion on episodic memory, see Chapter 19), including the simulation of future events. For example, most people have an *optimism bias*, or a general tendency to expect that positive things will happen to them in the future, as well as a corresponding inclination to underestimate the likelihood of negative events happening to them personally (Sharot, 2011). When participants imagine future events that have either positive or negative emotional connotations (e.g., "winning an award," or "the end of a romantic relationship"), positive events are perceived as being closer in time to the present than negative ones, and are also rated as eliciting a stronger sense of actually experiencing the event (Sharot *et al.*, 2007). Imagined events that have positive emotional connotations are more likely to be remembered across long delays when participants are asked about them later than are imagined events with negative connotations (Szpunar, Addis, and Schacter, 2012). These tendencies have been shown to be important for maintaining mental health, as the strength of a person's optimism bias is associated with overall wellbeing (Schweizer, Beck-Seyffer, and Schneider, 1999). Optimism bias is also negatively correlated with depressive symptoms, such that people who are more optimistic are less likely to experience symptoms of depression (Strunk, Lopez, and DeRubeis, 2006). The ability to imagine an optimistic future is therefore highly beneficial.

Summary

It is now firmly established that episodic memory and episodic simulation of the future have much in common. This conclusion is based on evidence that a variety of amnesic patients imagine future events that are less detailed than controls, that the neural bases of remembering and imagining have substantial overlap, and that two processes also share many cognitive features and processes. It is hypothesized that the constructive nature of episodic memory allows for details from past experiences to be rearranged and recombined into mental representations of new scenarios that have not yet occurred (Schacter and Addis, 2007). Despite the similarities between episodic remembering and imagining, it is, however, generally possible to distinguish between events that really happened and those that were simply imagined; real memories tend to contain more vivid sensory and perceptual detail, while imagined events are more conceptual and contain more thought- and emotion-related information.

Some current issues in this area of research revolve around the specific role of the hippocampus in imagining future events. While many amnesic patients with damage to the hippocampus are unable to construct detailed and coherent simulations of the future, some such patients are unimpaired, particularly those who sustained their hippocampal damage perinatally or in infancy. The particular task used to evaluate participants' ability to imagine the future may explain some of the inconsistencies, as might the precise nature and location of hippocampal damage. Despite these variable findings, the hippocampus is consistently active while participants imagine future events, and its role in this task may include binding, encoding, retrieval, spatial processing, or all of these processes. Further research will clarify the hippocampal contribution to episodic simulation.

Future research should also help to increase our understanding of the functions of episodic simulation. As we emphasized, this capability confers a number of advantages, including enhanced preparation for upcoming events, more farsighted decision making, the maintenance of personal goals, and improved mental health. However, episodic simulation is not without pitfalls: incomplete simulations sometimes contribute to inaccurate predictions of the future (e.g., Gilbert and Wilson, 2007) and also to mistakes in planning, such as the planning fallacy, where people underestimate how much time it will take to complete a task (e.g., Dunning, 2007). Consideration of both the benefits and limitations of future simulations led Schacter (2012) to characterize episodic simulation as an *adaptive constructive process*: it plays a functional role in cognition but can also create distortions or illusions as a consequence of doing so. The same can be also said about episodic memory. Studies that attempt to clarify the processes responsible for the benefits and limitations of both episodic simulation and episodic memory should broaden our understanding of how individuals remember the past and imagine the future.

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