Episodic Simulation of Future Events

Concepts, Data, and Applications

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This article focuses on the neural and cognitive processes that support imagining or simulating future events, a topic that has recently emerged in the forefront of cognitive neuroscience. We begin by considering concepts of simulation from a number of areas of psychology and cognitive neuroscience in order to place our use of the term in a broader context. We then review neuroimaging, neuropsychological, and cognitive studies that have examined future-event simulation and its relation to episodic memory. This research supports the idea that simulating possible future events depends on much of the same neural machinery, referred to here as a core network, as does remembering past events. After discussing several theoretical accounts of the data, we consider applications of work on episodic simulation for research concerning clinical populations suffering from anxiety or depression. Finally, we consider other aspects of future-oriented thinking that we think are related to episodic simulation, including planning, prediction, and remembering intentions. These processes together comprise what we have termed "the prospective brain," whose primary function is to use past experiences to anticipate future events.

Key words: **episodic memory; simulation of future events; neuroimaging; constructive memory; episodic future thinking; prospective memory; foresight; hippocampus; prefrontal cortex; mental time travel**

The study of episodic memory has constituted one of the most vigorous research areas in all of cognitive neuroscience for more than two decades. Neuroimaging and patient studies have examined a wide variety of topics, including the nature of encoding and retrieval processes, the relation between recollection and familiarity, and the basis of memory accuracy versus distortion, along with many others. During the past year or two, a less familiar topic has burst onto the landscape of memory research: the role of episodic memory in imagining or simulating possible future events. Though seeds of interest in the topic had been sown in earlier years, the simultaneous publication within a brief time span of neuroimaging, neuropsychological, and cognitive studies, as well as the appearance of several theoretically oriented integrative articles, has brought much greater attention to the issue.

The purpose of the present article is to consider this emerging collection of empirical findings and ideas in a broad context of relevant research, concepts, and applications. We will focus on the recent evidence indicating that episodic memory is critically involved in our ability to carry out simulations of future happenings and to imagine novel events, and that brain regions traditionally identified with memory, including the hippocampus, appear to be similarly engaged when people imagine future experiences. Because we have reviewed some of this work elsewhere (Buckner & Carroll 2007; Schacter & Addis 2007a; Schacter et al. 2007), here we will focus on delineating some of the key concepts in this emerging area and discussing research that we have not considered in our previous papers. We will also attempt to link work on episodic simulation to related research that fits under the rubric of an organizing concept that we have termed "the prospective brain," which proposes that a crucial function of the brain is to use stored information to allow us to imagine, plan for, and predict possible future events (Schacter et al. 2007). The recent studies alluded to above have

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focused on imagining or simulating future events, but these are only a subset of processes that are relevant to the prospective brain.

We will begin by focusing on the concept of *simulating* possible future events, which we believe is central to understanding the prospective brain. The concept of simulation has played an important role in a number of areas of psychology and cognitive neuroscience but has been relatively little used in memory research. We will consider its various uses in order to help sharpen our own conceptualization of the term. Next, we will review neuroimaging, neuropsychological, and cognitive studies that have examined future-event simulation and its relation to episodic memory. A major message of this research is that simulating possible future events depends on much of the same neural machinery—what we will refer to as a core network—as does remembering past events.

We will then consider the applications of this work for research concerning clinical populations suffering from anxiety or depression in which pathological future thinking is a central feature. Finally, we place the process of event simulation into the broader context of the prospective brain by considering briefly research concerning related processes of planning, prediction, and remembering intentions. We offer a few preliminary thoughts concerning how simulation may be related to these other key processes of the prospective brain.

Episodic Simulation: Delineating a Concept

Consider a scenario in which you are preparing a talk that you will give the following week to a small group of experts in your field. You are trying to decide whether to include a particular analysis in your talk: is it necessary to present the analysis to buttress your case, or will it simply complicate and slow down your talk? You imagine yourself giving this talk, standing in front of an audience in the room the conference was held in last year. You consider each of the experts who will likely be in the audience and imagine how they would react to your claims with and without the extra analysis slide. You remember vividly how one of these colleagues objected fiercely to one of your earlier talks when you did not include a similar analysis and try to figure out whether a similar response is likely in this new situation. You also recall hearing from a collaborator that one of the attendees who you do not know well is a stickler for details; you can envisage her questioning why you did not include the extra analysis. Though it will add length to the talk, these

imaginary exercises convince you to err on the side of caution and include the extra analysis. When that analysis turns out the following week to be crucial to addressing the concerns of these colleagues, you are quite pleased that you took the time to imagine the possible outcomes before giving the talk.

This fictional (though not unfamiliar) scenario illustrates what we have in mind when we talk about episodic simulation of future events: drawing on elements of past experiences in order to envisage and mentally "try out" one or more versions of what might happen. Though memory researchers have until recently paid scant attention to the nature and implications of such episodic simulations, the general notion of mental simulation has been discussed by investigators in a number of areas of psychology and cognitive neuroscience.

Perhaps the first researcher to invoke the construct of simulation in a cognitive neuroscience context was the Swedish brain physiologist David Ingvar (see also Buckner et al. 2008 and Schacter et al. 2007 for discussion of Ingvar's work). Ingvar (1979) described studies in which he and his colleagues observed high levels of blood flow in prefrontal cortex during a resting awake state in which subjects sat quietly with eyes closed. Observing that the activated prefrontal regions are involved in "programming our behavior in general," Ingvar (1979, p. 21) theorized that the activity observed during resting states reflects an internal connection between the past and the future: "On the basis of previous experiences, represented in memories, the brain—one's mind—is automatically busy with extrapolation of future events and, as it appears, constructing alternative hypothetical behavior patterns in order to be ready for what may happen." Further, claimed Ingvar, "the high frontal cortical flows . . . could be ascribed to a '*simulation of behavior,*' i.e., an inner anticipatory programming of several alternative behavioral modes prepared to be used depending upon what will happen" (p. 21).

Ingvar's use of the concept of simulation is quite similar to the one that we will adopt in this article, and his general interpretation of his early data (see also Ingvar 1985; Ingvar & Philipson 1977) receives strong support from recent research that we will consider. Nonetheless, Ingvar's ideas regarding memory-based simulation of future events were largely ignored by memory researchers of the day (an inspection of the Web of Science citation database turns up only a few scattered citations to his work among memory researchers through the late 1980s; cf. Olton 1989; Schacter 1987; Tulving 1985, 1987; Tulving et al. 1988; Wood 1987).

At around the same time as Ingvar discussed simulation of possible future behavior patterns, Amos Tversky and Daniel Kahneman stressed the importance of simulation in their pioneering research concerning the role of heuristics and biases in human decision making. Tversky and Kahneman (1973) reported classic studies showing that subjects' estimates of the likelihood of an event happening in the future were greatly influenced by the ease of retrieving similar examples from memory, a process that they termed "the availability heuristic." In closing their 1973 article, Tversky and Kahneman also briefly discussed a related heuristic that is used when people make judgments about rare or unique events in which similar instances are not available in memory. Here, individuals construct scenarios related to the target events, and the ease of scenario construction influences likelihood estimates, such that more easily constructed scenarios are judged to be more likely to occur in the future. A decade later, Kahneman and Tversky (1982) noted that this latter mechanism had been relatively neglected in prior research and called it the "simulation heuristic." According to Kahneman and Tversky (1982), "There appear to be many situations in which questions about events are answered by an operation that resembles the running of a simulation model" (p. 201). They suggested further that "A simulation does not necessarily produce a single story, which starts at the beginning and ends with a definite outcome." Instead, "we construe the output of simulation as an assessment of the ease with which the model could produce different outcomes" (p. 201). Commenting that contemporary understanding of the simulation heuristic "is still rudimentary," Kahneman and Tversky called for further research "in a domain that appears exceptionally rich and promising" (p. 204). Although there has been relatively little research on the simulation heuristic during the past 25 years, we will discuss later some interesting explorations of this heuristic in the future thinking of psychopathological populations (e.g., Brown et al. 2002; Raune et al. 2005; Vaughn & Weary 2002).

Note that Kahneman and Tversky's ideas about the simulation heuristic were not specifically restricted to future events; they also discussed the role of simulation in reconstructing and revisiting past events (i.e., counterfactual thinking; see also Byrne 2005; Kahneman & Miller 1986). Taylor and Schneider (1989) invoked an even broader notion of simulation in the context of a cognitive theory of coping and emotion regulation. They defined simulation as "the imitative representation of the functioning or process of some event or series of events . . . We will use the term to mean the cognitive construction of hypothetical scenarios or the reconstruction of real scenarios" (p. 175). Taylor and Schneider ascribed great functional importance to simulation because it provides a kind of cognitive flexibility that exceeds what can be accomplished by behavior alone: "Unlike actual behavior, the cognitive system is capable of rerunning past events, altering their components or changing their endings, and projecting multiple versions of imaginary or future events with considerable virtuosity" (p. 175). Taylor and Schneider went on to outline and discuss specific functions for simulation of future events, including checking the viability of plans (cf. Miller et al. 1960), regulating emotions, and facilitating links between thought and action. They also discussed how simulation of past events can aid coping with prior stressors (see Taylor et al. 1998 for an update; for related work, see Sanna 2000).

The foregoing uses of the concept of simulation have for the most part focused on simulation of particular episodes or events. An even broader use of the concept can be found in research exploring the hypothesis that thinking and categorizing involve the simulation of perception and action (Barsalou 1999, 2003; Hesslow 2002, for review see Decety & Grezes 2006). Thus, for example, Barsalou (2003, p. 521) argued that "conceptual processing uses reenactments of sensory-motor states—simulations—to represent categories." Hesslow (2002, p. 242) contended that conscious thought reflects the simulation of perception and action. For example, simulation of perception occurs in the sense that "imagining perceiving something is essentially the same as actually perceiving it, only the perceptual activity is generated by the brain itself rather than by external stimuli," whereas simulation of action occurs because "we can activate motor structures of the brain in a way that resembles activity during a normal action but does not cause any overt movement." Interestingly, these broad conceptions of simulation were influenced by early work from David Ingvar that showed similar patterns of cerebral blow flow when subjects carried out a movement and when they only imagined carrying out the movement. Decety and Ingvar (1990) provided a comprehensive review of then-extant studies concerning brain structures that participate in simulation of various kinds of actions. There has been considerable cognitive neuroscience research on the topic since that time (Decety & Grezes 2006) as well as on related topics such as the overlapping brain regions activated during perceiving and imagining (e.g., Kosslyn 1994, 2005).

Finally, the concept of simulation has played an important role in developmental research concerning theory of mind and related work on "mentalizing," or the processes involved in reading the mental states of

other individuals (for reviews, see Frith & Frith 2006; Goldman 2006; Oberman & Ramachandran 2007). This approach stems from philosophical analyses that emphasize the critical importance of simulation in mentalizing (Goldman 1989; Gordon 1986; Heal 1986). According to the simulation account, attributions about another individual's mental state involve imaginatively placing oneself in the other's situation and pretending to have the same desires or beliefs as the other individual (Goldman 2006). The results of this mental simulation can then be used to make predictions or inferences about how another individual will behave. The simulation account contrasts with the so-called theory-theory, which holds that folk psychology or commonsense theories about other individuals' minds constitute the basis for mentalizing (e.g., Gopnik & Meltoff 1997; Gopnik & Wellman 1992). Debates about the viability of simulation and theory-theory accounts of mentalizing in both children and adults remain active and unsettled (cf. Davies & Stone 1995; Goldman 2006; Gordon 1992; Heal 1994; Mitchell et al. 2006; Saxe 2005).

It seems clear, then, that the concept of simulation has been used in diverse settings and for a variety of theoretical purposes. In the present article, our use of the term "simulation" most closely resembles that of Taylor and Schneider (1989) in that we use the term to refer to *imaginative constructions of hypothetical events or scenarios*. We note several points about our use of the concept. First, we view simulation as a goal-directed process that involves more than simple imagery. People generate simulations with a view toward addressing a current or future problem. Second, we emphasize that simulation is critical for envisaging possible future events, but we do not restrict our application of simulation to the future. People also engage in simulations of present and past events, a point to which we return later when considering theoretical approaches to recent neuropsychological and neuroimaging data. Given the range of situations in which simulations are used, it would be easy to use the concept of simulation interchangeably with more general notions such as "thought" or "thinking." We view simulation as a particular kind or subset of thinking that involves imaginatively placing oneself in a hypothetical scenario and exploring possible outcomes. Third, we focus our review and theoretical claims on simulation of events or episodes. While acknowledging that others use the concept much more broadly to make claims about the nature and basis of perception, categorization, mentalizing, and the like, our own emphasis on episodic simulation is neutral with respect to the various theoretical debates that exist concerning these related issues. It

may turn out that there is a common underlying basis for various kinds of simulation-based processes, and we indeed consider later some data bearing on this point. We are hopeful that by delineating some key features of episodic simulation and suggesting a neural basis for this process that we can help to pave the way for a broader understanding of simulation processes is several domains.

Episodic Simulation of Future Events: The Core Network

The emerging interest in future-event simulation within cognitive neuroscience is no doubt attributable, at least in part, to recent studies that provide converging evidence for shared neural processes underlying remembering past events and imagining future events. These studies show, to varying degrees, that regions previously thought to play a role in episodic remembering, including prefrontal and medial temporal regions, are also implicated in simulation of future events. While a role for prefrontal cortex in future thinking dates to the early work of Ingvar (1979, 1985), observations of medial temporal contributions to future-event simulation are of more recent vintage. Relevant evidence has been provided by behavioral studies of amnesic patients and neuroimaging studies of individuals with intact memory.

The first indications that future-event simulation might rely on the same structures as episodic memory came from observations of amnesic patients. In his famous monograph concerning patients with Korsakoff's amnesia, Talland (1965) observed that many of his patients exhibited deficits in making personal plans. However, it was unclear from these observations whether and how the memory and planning deficits are linked. Patients with Korsakoff's syndrome often exhibit problems not observed in other amnesic patients as a result of their relatively more diffuse pathology (e.g., Schacter 1987; Squire 1982), and it is possible that the planning deficits are incidental or unrelated to the memory deficits. Somewhat more compelling evidence was provided by observations concerning the severely amnesic patient K.C., who fails to remember *any* specific episodes from his past (for a review of K.C., see Rosenbaum et al. 2005). Strikingly, K.C. showed a parallel difficulty envisaging any specific episodes in his future (Tulving 1985; Tulving et al. 1988). However, as with the Korsakoff patients, K.C. is characterized by fairly extensive brain damage, affecting medial temporal, prefrontal, and other regions; though

episodic memory loss clearly constitutes his most severe problem, it is not his only deficit (see Rosenbaum et al. 2005).

Klein et al. (2002) reported a more extensive investigation of past and future events in patient D.B., who became amnesic as a result of cardiac arrest and consequent anoxia. They gave D.B. a 10-item questionnaire probing past and future events that were matched for temporal distance from the present (e.g., What did you do yesterday? What are you going to do tomorrow?). Since it is not entirely clear what constitutes a correct answer for questions about the personal future, Klein et al. evaluated D.B.'s responses in light of information provided by his family. For example, D.B. was asked "When will be the next time you see a doctor?" and responded "Sometime in the next week." This response was judged correct because his daughter confirmed that he did have an appointment with the doctor the next week. D.B. was also asked "Who are you going to see this evening?" and said that he was going to visit his mother. This response was judged incorrect (i.e., confabulatory) because D.B.'s mother had died nearly two decades earlier. Consistent with the previous observations, D.B. was highly impaired on the both past and future versions of this task. D.B.'s deficit in simulating future events appeared to be specific to his *personal* future: D.B. showed little difficulty imagining possible future events in the public domain, such as political events and issues. As Schacter and Addis (2007b) have noted, however, many of the items concerning the public domain did not ask about specific events, so the evidence for a personal/public distinction is not clear cut. Furthermore, little information was provided concerning the location of D.B.'s lesion, limiting the inferences that could be made concerning the basis for the future simulation deficit and its relation to his episodic memory problems.

A number of the foregoing limitations were addressed in a more recent study by Hassabis et al. (2007). They examined the ability of five patients with documented bilateral hippocampal amnesia to imagine novel experiences. Amnesic patients and matched controls generated everyday imaginary experiences, such as "Imagine you're lying on a white sandy beach in a beautiful tropical bay." Subjects were specifically instructed to construct something new and not to provide a memory of a past event. Participants described their imaginary scenarios in the presence of a cue card to remind them of the task, and experimenters probed subjects for further details and elaboration. Protocols were scored based on the content, spatial coherence, and subjective qualities of the participants' imagined scenarios.

The imaginary constructions produced by four of the five hippocampal patients were greatly reduced in richness and content compared with those of controls. The impairment was especially pronounced for the measure of spatial coherence, indicating that the constructions of the hippocampal patients tended to consist of isolated fragments of information, rather than connected scenes. Interestingly, the one patient who performed normally on the imaginary scene task exhibited some residual hippocampal tissue, which may have contributed to the intact performance.

Compared with previous studies of amnesic patients, this study provides a tighter link between event simulation and brain function, since the lesions in these cases appear to be restricted to hippocampal formation. However, in contrast to the earlier observations, this study did not specifically require participants to construct scenes pertaining to *future* events, suggesting that the amnesic patients suffer from a more general event simulation deficit that pertains to constructing novel scenes irrespective of time period. Of course, the fact that the instructions for this study failed to specify a time period need not necessarily mean that participants did not imagine the scenes in a temporal frame. For example, when asked to imagine yourself on a white sandy beach, you might envision yourself taking next winter's vacation in a warm climate. We return to this point later when discussing various theoretical interpretations of future-event simulation.

Recent neuroimaging studies converge nicely with the data from amnesic patients in pointing toward regions that are associated with past and future-event simulation. An early neuroimaging study investigating future-event simulation was reported by Okuda et al. (2003). During a PET scan, participants were instructed to talk freely about either the near past or future (i.e., the last or next few days) or the distant past or future (i.e., the last or next few years). There was evidence of shared activity during past and future conditions in several prefrontal regions, as well as in the medial temporal lobe, including right hippocampus and bilateral parahippocampal gyrus. The effect of temporal distance on neural activity in these regions revealed that in eight out of the nine foci the same neural response to temporal distance (i.e., either an increase or decrease with increasing distance) was evident for both past and future events.

Although participants in this study talked about their personal past or future, it is unclear whether these events were episodic (unique events specific in time and place), rather than reflecting general or semantic information about one's past or future. More recent fMRI studies have used event-related designs to yield

information regarding the neural bases of specific past and future events.

Szpunar et al. (2007) instructed participants to remember specific past events, imagine specific future events, or imagine specific events involving a familiar individual (Bill Clinton) in response to event cues (e.g., past birthday, retirement party). Again, there was striking overlap in activity associated with past and future events in the bilateral frontopolar and medial temporal lobe regions, as well as posterior cingulate cortex. Importantly, these regions were not activated to the same magnitude when imagining events involving Bill Clinton, seeming to demonstrate a neural signature that is unique to the construction of events in one's *personal* past or future.

A point of general concern in studies that compare the neural correlates of remembering past events and imaging future events is that remembering is typically associated with greater levels of episodic detail than is imagining (e.g., Johnson et al. 1988). If so, then comparisons between past and future events may be partly or entirely confounded by differences in level of detail. To address this issue, Addis et al. (2007) attempted to equate experimentally the level of detail and related phenomenological features of past and future events. Also, taking advantage of the temporal resolution of fMRI, the past and future tasks were divided into two phases: (1) an initial construction phase during which participants generated a past or future event in response to an event cue (e.g., "dress") and made a button-press when they had an event in mind; and (2) an elaboration phase during which participants generated as much detail as possible about the event. The construction phase was associated with some common past–future activity in posterior visual regions and left hippocampus. During the elaboration phase, when participants focused on generating details about the remembered or imagined event, there was even more extensive overlap between the past and future tasks. Both event types were associated with activity in a network of regions including not only medial temporal (hippocampus and parahippocampal gyrus) and prefrontal cortex, but also in posterior cingulate and retrosplenial cortex.

Botzung et al. (in press) have recently reported data from an fMRI study that largely converge with those of the foregoing studies. The day before scanning, subjects initially reported on 20 past events from the previous week and 20 future events planned for the upcoming week. The subjects constructed cue words for these events, which were presented to them the next day during scanning, when they were instructed to think of past or future events related to each cue. Past and future events produced activation in a similar network to that reported by Addis et al. (2007), including precuneus, medial temporal, medial prefrontal, and dorsolateral prefrontal regions.

In light of these recent studies, it is interesting to note partly overlapping findings in an older study by Partiot et al. (1995) concerning what the authors termed "emotional and nonemotional plans." Subjects were asked to imagine a single nonemotional script ("the sequence of events and feelings concerned with preparation and dressing before [their] mother comes over for dinner") or an emotional script ("the sequence of events and feelings concerned with preparation and dressing to go to [their] mother's funeral"). Compared with linguistic and imagery control tasks, a number of regions similar to those documented in recent studies show increased activation, including dorsolateral prefrontal, left frontopolar, left precuneus/posterior cingulate, and right inferior parietal cortex for the nonemotional condition, medial prefrontal and cingulate for the emotional condition, and medial retrosplenial for both conditions. This study used only a single script for each condition, and it is unclear whether or not subjects imagined specific events; thus, the results must be interpreted with some caution. Nonetheless, there are clear points of overlap with more recent work.

Taken together and in relation to previous studies of autobiographical memory (Cabeza & St Jacques 2007; Gilboa 2004; Maguire 2001; Svoboda et al. 2006), these studies support the idea that a specific core network of regions supports both remembering the past and imagining the future (Buckner & Carroll 2007; Schacter et al. 2007; see FIGURE 1). Buckner et al. (2008), in this volume, provide a detailed analysis of the anatomy of this core network, which involves prefrontal and medial temporal lobe regions, as well as posterior regions including the posterior cingulate and retrosplenial cortex that are consistently observed as components of brain networks important to memory retrieval (Wagner et al. 2005).

Furthermore, analyses of the interactions among the brain regions within this core system demonstrate that many of the component regions are selectively correlated with one another within a large-scale brain system that includes the hippocampal formation (Buckner et al., 2008; Greicius et al. 2004; Vincent et al. 2006).

While the data support the idea that a brain system involving direct contributions from the medial temporal lobe supports both remembering the past and imagining the future, it is important to note that direct comparisons also provided some evidence for greater activity during imagining the future than remembering
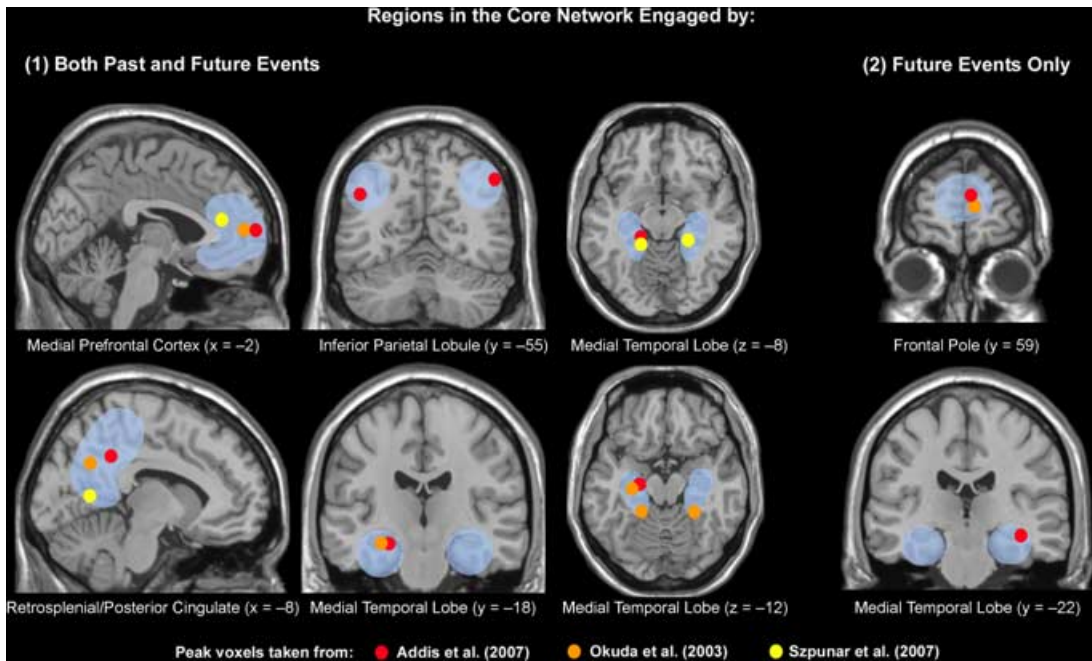
FIGURE 1. Regions making up the core network supporting the simulation of events are highlighted in blue, including medial prefrontal cortex, medial temporal lobe, retrosplenial/posterior cingulate cortex, and inferior parietal lobule. The regions making up this core network have been shown to functionally correlate with each other, and in particular, the hippocampus. Peak voxels from relevant contrasts in neuroimaging studies of past and future events (Addis et al. 2007; Okuda et al. 2003; Szpunar et al. 2007) are overlaid on the schematic of the core network. Included are peak voxels that exhibited (1) common responses to past and future events and (2) differential responses to future events relative to past events.

the past. Okuda et al. (2003) reported greater activity in frontopolar and medial temporal regions during future than past conditions. Szpunar et al. (2007) reported several regions that were significantly more active for future relative to past events, but not vice versa. Addis et al. (2007) found that during the early construction phase of future simulation, several regions showed greater activity for future versus past events (but not the reverse), including frontopolar cortex.

How can we interpret these findings? Szpunar et al. (2007) suggested that this pattern could reflect a more active type of imagery processing required by future than past events. Addis et al. (2007) hypothesized that the pattern reveals the more intensive constructive processes required by imagining future events relative to retrieving past events. While both past and future event tasks require the retrieval of information from memory, thus engaging common memory networks, only the future task requires that event details gleaned from various past events be flexibly recombined into a novel future event, perhaps resulting in increased activity during such tasks.

Note also that Botzung et al. (in press) found no evidence for future greater than past activation in any

region; in fact, they found that three regions of interest (right and left hippocampus and anterior medial prefrontal cortex) showed the opposite pattern. However, as noted earlier, in the Botzung et al. study—unlike those of Addis et al., Okuda et al., and Szpunar et al.— subjects initially carried out their simulations of future events in a separate session prior to scanning. During scanning, subjects may have recalled their prior simulation, rather than constructing it for the first time, as subjects did in earlier studies. Botzung et al. attempted to address this issue by asking subjects whether they produced the original past or future event during scanning, or the descriptions of those events from the prescan interview; they excluded those trials where subjects stated that they produced an event from the prescan interview. Nonetheless, since subjects had previously encoded their future-event simulation, rather than constructing it during scanning as in previous studies, there may have been less recruitment of processes involved in recombining details from past experiences. If so, it is perhaps not surprising that they failed to observe the neural correlates of such processes, that is, greater activity for future than past events. Indeed, in an earlier electrophysiological study of memory for previously

imagined versus previously experienced events, Conway et al. (2003) reported evidence of greater activity in posterior regions for experienced than imagined events. Additional research is required to compare online construction of imagined events and memory for imagined events.

Further evidence concerning differential neural responses to past and future events comes from a study by Addis and Schacter (2008) that examined further the responses of several regions of interest from the Addis et al. (2007) study. While emphasizing the theoretical importance of the overlapping network of regions activated during elaboration of past and future events, Addis and Schacter also noted the possibility that regions within the network respond differently to particular event characteristics, such as temporal distance and the amount of detail generated, depending on whether the event is in the past or future. Addis and Schacter explored the issue by conducting parametric modulation analyses, with temporal distance and detail as covariates, focusing on the medial temporal lobes and the frontopolar cortex. They hypothesized that the integration of increasing amounts of detail for either a past or future event would be associated with increasing levels of hippocampal activity. Moreover, because future events are thought to require more intensive processing to recombine disparate details into a coherent event, the hippocampal response to increasing amounts of future-event detail should be larger than that for past-event detail. In addition, since the right frontal pole is thought to play a role in prospective thinking (e.g., Burgess et al. 2001; Okuda et al. 2003), this region should also exhibit a future–past detail response if it is involved in the generation of future details.

Consistent with predictions, the analysis showed that the left posterior hippocampus was responsive to the amount of detail comprising both past and future events. In contrast, a separate region in the left anterior hippocampus responded differentially to the amount of detail comprising future events, possibly reflecting the recombination of details into a novel future event. Moreover, the right frontal pole responded significantly more to the generation of future relative to past-event details, suggesting that this region might be involved specifically in prospective thinking.

The parametric modulation analysis of temporal distance revealed that the increasing recency of past events was associated with activity in the right parahippocampus gyrus (BA 35/36), while activity in the bilateral hippocampus was associated with the increasing remoteness of future events. Addis and Schacter proposed that the hippocampal response to the distance of future events reflects the increasing disparateness of details likely included in remote future events and the intensive relational processing required for integrating such details into a coherent episodic simulation of the future. More generally, these results suggest that the core network supporting past- and future-event simulation can be recruited in different ways depending on whether the generated event is in the past or future.

This latter observation raises a general point concerning the growing number of studies that have compared remembering the past with imagining the future. When differences between these two conditions are observed, they are typically attributed to differences in the way the brain handles past and future events. However, because in the reviewed studies past events are remembered whereas future events are imagined, the differences could equally well be attributed to differences between remembering and imagining, rather than differences between past and future per se. Of course, the future cannot be remembered because it has not yet happened. However, both the past and the future can be imagined. Therefore, it would be useful for researchers to consider including conditions in their experiments in which participants imagine events as having occurred in the past; any past–future differences observed under these conditions cannot be attributed to differences between remembering and imagining. Such a comparison should allow further refinement of theoretical conclusions concerning how the brain simulates events.

Cognitive Neuroscience of Episodic Simulation: Theoretical Accounts

The foregoing observations have led to several recent hypotheses regarding the nature of episodic simulation and the brain regions that support it. Two different types of theoretical accounts can be distinguished: one type is concerned primarily with understanding the relation between past and future events; the second type is concerned with specifying the critical conditions under which the core network is activated and understanding the functions served by this network. Though the two types of accounts are related, they focus on slightly different questions and different data sets.

Perhaps the best known attempt to link past and future events is Tulving's notion of "mental time travel" (e.g., Tulving 1983, 2002, 2005). From this perspective, remembering past experiences and simulating future events are linked because they both depend on

an episodic memory system that allows individuals to detach from the present environment and project themselves into the past or the future. This view accounts naturally for the overlap in brain regions activated during past and future events and for the parallel past–future deficits observed in amnesic patients. The hypothesis is also supported by developmental studies indicating both episodic remembering and future thinking emerge roughly in parallel, between approximately three and five years of age (Atance & O'Neill 2005; Suddendorf & Busby 2005), and by cognitive studies that have shown that remembering past events and imagining future events are affected similarly by a number of experimental manipulations. For example, in a study of college students, D'Armgembeau and van der Linden (2004) found that positive events were associated with increased subjective ratings of reexperiencing for past events and "preexperiencing" for future events and that temporally close events in either the past or future included more sensory and contextual details, and greater feelings of reexperiencing and preexperiencing, than temporally distant events (see also Nussbaum et al. 2006; Trope & Liberman 2003). D'Argembeau and van der Linden (2006) showed that individual differences in imagery ability and emotion-regulation strategies are similarly related to past and future events. Spreng and Levine (2006) reported striking similarities in the shapes of the temporal distributions of past and future autobiographical events provided by college students and older adults.

Much discussion regarding mental time travel has centered on the question of whether nonhuman animals exhibit this ability. Tulving (2005) and others (e.g., Suddendorf & Corballis 1997, 2007) have argued strongly that the capacity for mental time travel is uniquely human. While acknowledging that nonhuman animals can use stored information by relying on semantic or procedural memory systems, they contend that such processes need not involve mental time travel in the sense of detaching oneself from the present moment and either recollectively reexperiencing a past event or simulating and "preexperiencing" a future event. In fact, Tulving (2005) and Suddendorf and Corballis (1997, 2007) argued that animals lack the episodic memory capacities required for time travel into past or future. This strong claim has spurred research examining whether nonhuman animals are capable of mental time travel (for recent reviews, see Clayton et al. 2003; Suddendorf & Corballis 2007), including compelling experimental demonstrations that, at the very least, cast doubt on the strong claim for human uniqueness. For example, Clayton and Dickinson (1998) showed that food-caching scrub jays are able

to retrieve detailed information about what food they cached as well as when and where they cached it. More recently, they have devised clever paradigms that establish that jays can cache food in a manner that reflects some form of planning for the future (Raby et al. 2007). Further, they have carried out control tasks indicating that such planning-like behavior is not merely a reflection of the jays' current motivational state (Correia et al. 2007). There is also evidence from rats that suggests some of type of prospective coding. Ferbinteanu and Shapiro (2003) recorded hippocampal activity during a spatial task that required them to find food at the end of a goal arm; multiple trials were performed at each goal arm. The investigators reported evidence that the hippocampal neurons encoded not only current location and recent memory, but also prospective information concerning where the rat needed to go in the immediate future. More recently, Diba and Buzsaki (2007) recorded hippocampal activity while rats ran back and forth on a track to obtain a water reward at each end of the track. At the end of a run, they found that hippocampal neurons exhibited "reverse replay" (Foster & Wilson 2006) of the route, firing in reverse order of activity during the run. In addition, Diba and Buzsaki also found evidence that hippocampal neurons exhibited "forward preplay" in anticipation of an upcoming run, perhaps suggesting the formulation of some type of route planning. Johnson and Redish (in press) reported similar phenomena in a cleverly designed series of experiments that examined place cell activity during choices made by rats in spatial decision tasks. They recorded from ensembles of neurons with place fields in the CA3 region of hippocampus, allowing them to analyze activity at critical decision points. They found that on some trials, the spatial representation reconstructed from the neural ensemble "swept ahead" of the animal, appearing to indicate possible future paths. These observations lead the authors to suggest that the hippocampus may provide prospective memory signals that serve as a basis for making decisions.

Suddendorf and Corballis (2007) provided a conceptual "theater production metaphor" to promote discussion of whether nonhuman animals are capable of mental time travel. They liken the experience of envisioning the future or recollecting the past to a theater production involving several key components: a stage on which the production unfolds (working memory), a playwright who scripts the production (combining and recombining stored information), actors who play characters in the production (knowledge of self and others), a set that reflects aspect or principles of the real world (knowledge of time), a director who

tries out different versions of the production (monitoring and metacognition), an executive producer who organizes high-level aspects of the production (executive control), and a broadcaster who communicates the production (language or nonlinguistic communication). Suddendorf and Corballis considered the extent to which nonanimals possess each of these critical components of mental time travel.

We think that this theater production metaphor constitutes a useful approach to addressing issues of mental time travel in animals. As we have argued elsewhere (Schacter et al. 2007), however, it is unclear whether debates about mental time travel in nonhuman animals will ever be settled definitively, given that animals do not possess the linguistic capacity to describe mental contents (or without detailed measurements of neural activity that reflects mental content). From a theoretical perspective, however, this aspect of the mental time travel hypothesis—that is, can nonhuman animals engage in mental time travel—can be treated separately from issues concerning how well the hypothesis handles data from human subjects. For example, Suddendorf and Corballis's theater production metaphor may prove a useful heuristic for thinking about mental time travel independent of how questions concerning mental time travel in animals are ultimately resolved. Similarly, a critical question concerns whether mental time travel specifically or uniquely activates the core network. Although Tulving (2002, 2005) has not made any strong claims on this score, the core network does appear to be involved in functions other than those strictly involving mental time travel.

Several recent proposals have considered the functions of regions within the core network in a range of simulation processes (Buckner & Carroll 2007; Hassabis et al. 2007; Hassabis & Maguire 2007; Schacter & Addis 2007a, 2007b). Schacter and Addis (2007a, 2007b) focused on the constructive processes involved in future-event simulations, suggesting that this property of adaptive simulations could help to explain why memories for the past are subject to errors and misattributions. Buckner and Carroll (2007) focused on the anatomy of the core network and its generality across many tasks that demand mental simulations, including but extending beyond those that are simulations of the past and future. Hassabis and Maguire (2007) explored the degree to which a proposed form of mental imagery—scene construction—is the common process linking together various tasks that depend on the core network. We discuss each of these ideas in more detail below.

The *constructive episodic simulation hypothesis* (Schacter & Addis 2007a, 2007b) maintains that simulation of

future events requires a system that can flexibly recombine details from past events. The idea was proposed in the context of attempting to understand why memory involves a constructive process of piecing together bits and pieces of information, rather than a literal replay of the past. The constructive nature of memory can result in various kinds of errors and distortions (e.g., Bartlett 1932; Loftus 2003; Roediger & McDermott 1995; Schacter 1999, 2001). However, it has also been suggested that some of these memory errors serve an adaptive role (cf. Anderson & Schooler 1991; Bjork & Bjork 1988; Schacter 1999, 2001). For example, Anderson and Schooler (1991) argued that memory is adapted to retain information that is most likely to be needed in the environment in which it operates. Because we do not often need to remember all the exact details of our experiences, an adapted system would not automatically preserve all such details. Thus, by producing what we can think of as data compression or economy of storage, a constructive memory system may promote adaptive functions.

Arguing from a different kind of adaptive perspective, Schacter and Addis (2007a, 2007b) suggested that a critical function of a constructive memory is to make information available for simulation of future events (see also relevant discussion by Dudai & Carruthers 2005; Suddendorf & Corballis 1997). By this view, past and future events draw on similar information stored in episodic memory and rely on similar underlying processes; episodic memory supports the construction of future events by extracting and recombining stored information into a simulation of a novel event. The adaptive value of such a system is that it enables past information to be used flexibly in simulating alternative future scenarios without engaging in actual behavior. A potential downside of such a system is that it is vulnerable to memory errors, such as misattribution and false recognition (see, e.g., Schacter & Addis 2007a, 2007b). While focusing on processes that support future-event simulation, the constructive episodic simulation hypothesis does not explicitly embrace or reject the idea that the core network is specifically involved in mental time travel.

The constructive episodic simulation hypothesis receives general support from the previously reviewed findings of neural and cognitive overlap between past and future events. Further support is provided by recent data from Szpunar and McDermott (in press). They reported more vivid and detailed future-event simulations when college students imagined events that might occur within the next week in a familiar context (home, friend's apartment) than in a novel context (jungle, North Pole), and also that future events

were more vivid and detailed when imagined in recently experienced contexts (university locations) than in remotely experienced contexts (high school). Familiar and recently experienced contexts are usually represented in greater episodic detail than novel and remote ones. Accordingly, these results support the idea that episodic information is used to construct future-event simulations.

Because the constructive episodic simulation hypothesis specifically emphasizes the importance of flexibly relating and recombining information from past episodes, it is supported by the evidence discussed earlier that links hippocampal function and relational processing with future-event simulation. The hippocampal region is thought to support relational memory processes (e.g., Eichenbaum & Cohen 2001), and these processes are hypothesized to be crucial for recombining stored information into future-event simulations. Further support along these lines comes from a behavioral study of future-event simulation in older adults. Addis et al. (2008) provided younger and older adults with event cues and provided them three minutes to generate, in as much detail as possible, episodes from specified periods in the past or future. Consistent with previous work (Levine et al. 2002), older adults reported less detailed episodic memories of past events than did younger adults. A parallel effect occurred for future events: the episodes imagined by older adults also contained sparser episodic information compared to younger adults. Critically, as predicted by the constructive episodic simulation hypothesis, the ability of older adults to generate episode-specific details of both the past and future events was correlated with a measure of their ability to integrate information and form relations between items—that is, with their relational memory performance.

While the available data are thus consistent with the constructive episodic simulation hypothesis, a number of issues need to be addressed. For example, it remains unclear whether and to what extent future-event simulations are based on retrieval of individual fragments of prior episodes, or whether recombining elements from different episodes, as emphasized by the constructive episodic simulation hypothesis, is a critical process in future-event simulation. Also, the constructive episodic simulation hypothesis is likely incomplete because it emphasizes the contribution of episodic memory to future-event simulation, while remaining mute about possible contributions of semantic memory. Although the distinction between episodic and semantic memory continues to inspire debate and discussion (cf. Foster & Jelicic 1999; Moscovitch et al. 2006; Tulving 1983, 2002), it seems clear that as the source of knowledge

about general properties of events, semantic memory presumably is used to guide the construction of future scenarios in line with known event properties. Research that directly compares episodic and semantic contributions to future-event simulations may well require extension or modification of the constructive episodic simulation hypothesis. Finally, while the constructive episodic simulation hypothesis holds that there is a direct link between future-event simulation and memory distortion, no such link has yet been established empirically.

While sharing some of the core assumptions of the constructive episodic simulation hypothesis regarding the use of episodic information to build future-event simulations, other theories have focused on broader issues concerning the conditions under which the core network is engaged. Buckner and Carroll (2007) argued that the core brain system serves a common set of processes by which past experiences are used adaptively to imagine perspectives and events beyond those that emerge from the immediate environment. In addition to the system's role in remembering the past and envisioning the future, they argued, it serves an even more general function, extending to diverse tasks that require mental simulation of alternative perspectives. They observed that regions within the core network, in particular the posterior cingulate/retrosplenial region, are engaged during theory-of-mind tasks that require thinking about the perspectives of others (e.g., Saxe & Kanwisher 2003), and also noted that such regions may be engaged in certain kinds of spatial navigation tasks (e.g., Byrne et al. 2007). In light of these results, the mental time travel hypothesis seems too restrictive to accommodate the range of conditions in which the core network is active. Buckner and Carroll suggested that the core brain network is commonly engaged when individuals are simulating alternative perspectives, including alternatives in the present and possibilities in the future—a process they provisionally termed "self-projection." By this view, the core brain system allows one to shift from perceiving the immediate environment as constrained by the external world to an alternative, imagined perspective that is based largely on memories of the past. This view encourages further analysis of the common features of the various tasks subserved by the core network, including to what extent imagined perspectives always include visual imagery and self-referential processes. A clear prediction from this view is that activation of the core network should correspond to the extent that a task encourages simulation of an alternative perspective not required by the immediate environment.

It is interesting to note, however, that even though certain regions within the core network are active during theory-of-mind tasks (Saxe & Kanwisher 2003), Bird et al. (2004) reported that a patient with damage to part of the network (the medial prefrontal region) and who exhibited "severe" memory problems, nonetheless performed normally on theory-of-mind tasks. These observations contrast with those indicating that amnesic patients have difficulty simulating future events and raise questions concerning which regions in the core network (if any) are *necessary* for carrying out the kind of perspective taking involved in theory-of-mind tasks. Furthermore, these findings suggest that imagining the future may depend on remembering the past in a way that adopting the perspective of others does not. Analysis of functional connectivity provisionally suggests that medial prefrontal and medial temporal subsystems within the core network make distinct contributions to simulation (Buckner et al. 2008). Therefore, a full understanding of the roles of these individual regions within the core network is still evolving.

Hassabis and Maguire (2007) advanced a related though distinct view that "scene construction" is the critical process associated with activation of the core network, thereby emphasizing the visual–spatial aspects of the simulation. This view was motivated in part by the finding that amnesic patients showed deficits on a task that required them to imagine novel scenes (Hassabis et al. 2007); the spatial coherence of patients' constructions were particularly impaired. Further, Hassabis and Maguire (2007) refered to a neuroimaging study they conducted using their novel-scenes task that produced activation of the core network, both when subjects constructed novel scenes and when they remembered actual experiences. Critically, the novel-scenes task does not explicitly require mental time travel, thereby leading Hassabis and Maguire to contend that projecting oneself into the past or the future is not the critical process for activating the core network, similar to Buckner and Carroll's proposal. Hassabis and Maguire went on to argue that scene construction, rather than self-projection, can best account for the array of findings noted earlier without postulating that the scenes are referenced to a personal perspective. Further research will be required to determine whether scene construction is sufficient to account for all findings associated with the core network, including observations that the some regions in the network are used during forms of mentalizing, such as theory-of-mind tasks whose underlying processes are presently unclear.

Cognitive Neuroscience of Episodic Simulation: Applications and Extensions

The foregoing findings and ideas have begun to establish a foundation for understanding the brain systems involved in episodic simulation of future events. We now consider some applications and extensions of this work. First, we consider future-event simulation in psychopathological conditions—depression, anxiety, and schizophrenia. This has been an active area of research, including some of the earliest work on simulation of future events; we believe that recent cognitive neuroscience research has some interesting implications for this research. Second, we consider future-event simulation in relation to other processes that comprise the "prospective brain": the formation of plans and intentions, and making predictions about future events.

Simulation of Future Events: Relation to Psychological Well-Being and Psychopathology

Simulations play an important role in psychological well-being. The ability to generate specific and detailed simulations of future events is associated with effective coping; it enables one to engage in emotional regulation and appropriate problem-solving activities (Brown et al. 2002; Taylor et al. 1998; Taylor & Schneider 1989). Simulating future events can regulate emotion by allowing one to envision the feeling of relief associated with a positive outcome. For instance, coherent and detailed simulations of positive future outcomes have been found to correlate with increased subjective probability of a positive outcome and decreased amounts of worry related to the future event (Brown et al. 2002). Simulations can also enable identification of problem-solving activities. For instance, subjects who simulated the details of an ongoing stressful event were found to subsequently increase their use of active coping strategies and seeking social support, compared with participants who simulated the relief of the stressor resolving or with controls who did not engage in future-event simulation (Taylor et al. 1998). Moreover, simulating future stressful situations and mentally rehearsing appropriate actions in these situations can enhance one's ability to cope if and when those situations arise (Taylor & Schneider 1989).

These observations fit well with the results of a recent fMRI study by Sharot et al. (2007), who examined

the relation of future-event simulation to optimism—specifically, the pervasive optimistic bias whereby people maintain unrealistically positive expectations of their futures (Weinstein 1980). During scanning, 15 healthy young subjects were given brief descriptions of significant events, such as "the end of a romantic relationship" or "winning an award," and were cued to think about either a past event that had actually occurred or a future event that might occur. Subjects made a button-press response when the memory or simulation began to take shape, and then again when it was fully formed. They also rated each event for its emotional valence (positive, neutral, or negative). After the scanning session, subjects provided additional ratings concerning their memories and simulations: how vivid they were, how strongly they felt they were reliving their pasts or "preexperiencing" their futures, the time of the event, and their subjective sense of how close in time they felt to the event. Finally, subjects also completed a scale that assessed their degree of optimism (Scheier et al. 1994).

Behavioral data showed that a) subjects felt that positive future events were closer in time than negative future events, b) they rated positive events in the future as more positive than positive events from the past, and c) they indicated that positive future events were more intensely "preexperienced" than negative future events. These effects were strongest in the most optimistic subjects. The fMRI results revealed a possible brain basis for these optimistic biases. Several regions in the core network discussed earlier showed similarly increased activity when subjects recalled past events and imagined future events, including rostral anterior cingulate cortex (rACC) extending into ventral medial prefrontal cortex, dorsal medial prefrontal cortex, and posterior cingulate cortex. There was also significant activation in the amygdala. The amygdala as well the rACC showed less activity when people imagined negative future events compared with any of the other conditions (positive future events, positive past events, or negative past events). When people imagined positive future events, the activities of the rACC and the amygdala were more strongly correlated with one another than when the subjects imagined negative future events. Importantly, more optimistic individuals showed relatively greater rACC activation when imagining positive versus negative future events than did less optimistic individuals.

The results thus provide clues concerning the neural underpinnings of optimistic bias by showing that areas involved in emotional processing (amygdala and rACC) selectively decrease their activity when people think about negative future events and co-ordinate ac-

tivity when people think about positive future events, and that these effects are most pronounced in the most optimistic individuals. Given other behavioral evidence indicating that anticipating both negative and positive future events can be more emotionally intense than remembering negative and positive events (Van Boven & Ashworth 2007), additional studies are needed to delineate the conditions under which future-event simulations are associated with optimistic biases (for more detailed discussion of the Sharot et al. findings and their possible implications for understanding optimism, see Schacter & Addis 2007c).

Given the role of simulations in healthy and effective coping, it is not surprising that maladaptive coping strategies and psychopathological disorders are associated with changes in the ability to generate future simulations. To date, most theories advanced to explain simulation deficits in psychiatric disorders have focused on psychological and cognitive factors. We suggest that emerging knowledge concerning the neural regions supporting the simulation of past and future events provides a basis for formulating hypotheses regarding the mechanisms underlying simulation deficits in some psychiatric populations.

In an early study, Williams et al. (1996) reported that suicidally depressed patients have difficulty recalling specific memories of past events and also in generating specific simulations of future events. The past and future events generated by depressed patients in response to cue words lacked detail and were "overgeneral" relative to those produced by nondepressed controls. Importantly, the reductions in specificity of past and future events were significantly correlated. Numerous studies have since replicated the finding of reduced specificity and increased overgenerality of past and future events, not only in patients with major depressive disorder (Williams et al. 1996), but also those with mild depression (e.g., Dickson & Bates 2005; MacLeod et al. 1993), schizophrenia (D'Argembeau et al. in press), and depressed patients with borderline personality disorder (Kremers et al. 2006). Similarly, the worries of anxious individuals often exhibit reduced concreteness compared with those of healthy individuals (Stöber & Borkovec 2002).

In order to explain decreases in the specificity of simulated events in depression, Williams and colleagues (Williams 1996, 2006; Williams et al. 1996) advanced the *affect regulation hypothesis*. According to this hypothesis, the production of overgeneral events reflects the truncation of the event search as a protective mechanism to prevent retrieval of potentially destabilizing memories. The search for an event may be aborted at various stages of the retrieval process, as reflected

by the search output. For example, an omission would result if the search for an event is not initiated at all, whereas a general event would be produced if an initial search is completed but not further refined to locate a specific event. Moreover, ruminating on general events may cause "mnemonic interlock": when an individual cannot inhibit all the generic representations activated so that the search for a specific event can continue (Williams 1996, 2006). The affect regulation hypothesis is supported by studies reporting that specific memories of negative events cause more stress than general memories (Raes et al. 2003), and also by findings of more severe reductions in event specificity in individuals with a history of trauma (Kuyken & Brewin 1995; Raes et al. 2005) and those with a repressive coping style (Dickson & Bates 2005).

The neural mechanisms that might underlie the use of an overgeneral affective regulation have not been identified. However, one electrophysiological study of memory retrieval in healthy adults does lend support to the affect regulation hypothesis. Using event-related potentials, Conway et al. (2001) found that immediately following cue presentation emotional memories were associated with less activity across the prefrontal cortices as well as longer retrieval latencies. These findings were interpreted as reflecting an initial inhibition of the retrieval process due to the potentially destabilizing nature of emotional memories.

Williams et al. (1996) found that past and future events generated by suicidally depressed patients were overgeneral irrespective of the valence of the event. However, others have reported effects of valence, particularly with respect to the ease of access to future events. For instance, MacLeod et al. (1993) found that suicidally depressed patients were less able to envision *positive* future episodes. Similarly, dysphoric individuals took significantly longer to access pleasant past and future events but did not differ from controls with respect to unpleasant events (Dickson & Bates 2006). Moreover, slower and less successful access to positive future events, as well as the belief that positive future events are less likely to happen, has been found to correlate with the severity of hopelessness (MacLeod & Cropley 1995). This observation suggests that simulation deficits may be critical in maintaining the sense of hopelessness often evidence in depression.

Pessimistic views of the future have also been shown to play a role in psychiatric disorders. For instance, the severity of depression correlates with faster and more successful access to negative future events and a belief that negative events will happen in future (MacLeod & Cropley 1995). Moreover, dysphoric individuals have easier access to reasons why negative events will hap-

pen in future relative to nondepressed controls (Vaughn & Weary 2002). Similarly, increased access to simulations of negative future events is a characteristic of anxiety disorders (e.g., MacLeod et al. 1997; Ruane et al. 2005), including post-traumatic stress disorder (Lavi & Solomon 2005). In line with our earlier discussion of the simulation heuristic, whereby more easily constructed scenarios are judged to be more likely to occur in the future (Kahneman & Tversky 1982), the ability of anxious patients to gain access to simulations of negative future events, and to form visual images of the event, was found to correlate significantly with their predicted probability that these events would occur in the future (Ruane et al. 2005). Moreover, anxious patients were less able to generate reasons why negative events would *not* happen, relative to nonanxious controls (MacLeod et al. 1997). Pessimism has also been shown to differentiate anxiety from depression. Using a verbal fluency paradigm in which patients were required to generate as many positive and negative, past and future events as possible, MacLeod et al. (1997) found that anxious patients generated significantly more negative events than did controls, but not fewer positive events, while depressed patients generated significantly fewer positive events but not more negative events.

While applicable to mood disorders, the role of maladaptive affect regulation and pessimism is not as easily applicable to other psychiatric populations exhibiting simulation deficits, such as schizophrenia. In a recent study, D'Argembeau et al. (in press) found that schizophrenic patients generated significantly fewer specific past and future events than did healthy controls. Such observations encourage consideration of the possible role of factors other than affect regulation in the simulation deficits that are evident in psychiatric disorders, such as neuropsychological impairments that have been documented in psychiatric populations. While it is highly likely that affect regulation and pessimism influence the valance of future events accessible to patients with mood disorders, understanding the neural regions mediating the simulation of past and future events enables the generation of specific predictions regarding the neuropsychological deficits that may contribute to the reduced specificity of events evident in psychiatric disorders. This approach will hopefully enable development of integrative theories for understanding simulation deficits across various neuropsychological and psychiatric populations.

One such hypothesis is that executive dysfunction plays a critical role in simulation deficits. In this view, the search for a specific past or future event fails, not because it is truncated by affect regulation processes,

but because the patient fails to engage effective search processes as a consequence of executive dysfunction (Dalgleish et al. 2007; Hertel 2000). Simulation of an event is a relatively unconstrained task that places many demands on executive functions, including devising strategies to aid specification of effective cues, determining whether the simulated event meets the search criteria (e.g., a specific, plausible event), and inhibiting output which does not meet these criteria. Although reduced specificity of past events has been shown to correlate with reduced performance on executive tasks such as verbal fluency in depressed patients (Dalgleish et al. 2007), neither past nor future simulation deficits in schizophrenic patients correlated with verbal fluency measures (D'Argembeau et al. in press). Further research is needed to clarify the role of executive dysfunction in simulation deficits.

The recent data considered earlier from neuroimaging studies and amnesic patients, implicating the hippocampus as part of the core network subserving event simulation, suggest that hippocampal dysfunction might also contribute to overgeneral simulations of past and future events. Hippocampal atrophy and/or elevated hippocampal glucocorticoid levels are evident in a number of psychiatric conditions in which simulation deficits have been documented, including depression (Bremner et al. 2000; Campbell & Macqueen 2004), post-traumatic stress disorder (Sapolsky 2000), and schizophrenia (Velakoulis et al. 2006). Given that the hippocampus is crucial to the reintegration of details in order to recollect a specific past event and thought to be necessary for the recombination of details into a simulation of a specific future event (Addis et al. 2007, in press; Buckner & Carroll 2007; Hassabis et al. 2007; Schacter & Addis 2007a, 2007b), the various ideas discussed earlier suggest that hippocampal dysfunction is a candidate neural mechanism for simulation deficits observed in psychiatric populations.

A link between hippocampal dysfunction and relational memory deficits has been documented in some psychiatric disorders. For instance, fMRI studies have demonstrated that schizophrenic patients exhibit underrecruitment of the hippocampus during relational memory tasks, including transitive inference tasks that require flexible use of previously learned information (Öngür et al. 2006). However, despite the central role of the hippocampus in the simulation of past and future events, the link between reduced autobiographical event specificity and hippocampal dysfunction has been considered only occasionally in the psychiatric literature (Barnhofer et al. 2005). Further studies are needed to determine whether ability to generate spe-

cific simulations of past and future events is correlated with the structural and functional integrity of the hippocampus, as well as other regions comprising the core network that supports future-event simulation.

Finally, the Sharot et al. (2007) experiment concerning neural correlates of optimism, which we discussed earlier, fits nicely with studies indicating that depressed patients show reduced volume and metabolism in the same subregion of the rACC that Sharot et al. found to correlate strongly with optimism. When corrected for volume loss, metabolism in remaining rACC tissue is actually elevated in depressed patients relative to controls, and effective antidepressant treatment reduces rACC metabolism to normal levels (for review, see Drevets 2000).

Plans and Intentions: Links to Episodic Simulation?

We have emphasized that cognitive neuroscience research on episodic simulation of future events, though not without historical precedent, is of relatively recent vintage, with a good deal of focus on the topic emerging in the past couple of years. However, this is not to say that psychologists and cognitive neuroscientists have only recently begun to focus on future-oriented cognitive and memory processes; far from it. For example, cognitive and social psychologists have long been interested in the processes underlying planning (e.g., Miller et al. 1960; Morris & Ward 2005), and neuropsychologists and neurologists have conducted numerous studies of planning deficits in patients with frontal lobe lesions (e.g., Fellows & Farah 2005; Luria 1966; Mesulam 2002; Shallice 1982; Shallice & Burgess 1996; Stuss & Benson 1986). Similarly, for the past 20 years or more, cognitive psychologists and neuropsychologists have been interested in how people formulate and remember intentions to carry out future actions, an area of research that has come to be known as prospective memory (e.g., Brandimonte et al. 1996; Einstein & McDaniel 1990, 2005; Harris 1984).

What is the role of future-event simulation in such prospective processes? For the most part, researchers in the areas of planning and prospective memory have focused on issues other than episodic simulation. For example, planning researchers have examined the role of executive control and working memory processes in complex problem-solving tasks such as the Tower of London (e.g., Owen 2005; Philips et al. 1999; Shallice 1982), the relations among various kinds of planning tasks (e.g., Burgess et al. 2005), and the role of top-down and bottom-up processes in formulating and

executing plans (e.g., Hayes-Roth & Hayes-Roth 1979). Prospective memory researchers have spent a good deal of time examining such issues as the properties of cues that trigger recall of intentions, how individuals generate their own cues, the processes involved in monitoring whether an action needs to be performed, and distinctions among different types of prospective memory, such as event-based (remembering to carry out a task when a specific event occurs) versus time based (remembering to carry out an action at a specific time in the future; for review, see Brandimonte et al. 1996; Einstein & McDaniel 2005). Some of the issues have been studied from a cognitive neuroscience perspective with neuroimaging techniques. For example, Simons et al. (2006) asked whether the processes involved in recognizing the appropriate context to act (cue identification) and remembering the action to be performed (intention retrieval) have a common neural basis. They reported evidence that the frontal pole (BA 10) exhibited similar responses to cue identification and intention retrieval: in lateral BA 10, these two tasks resulted in increased activity, while in medial BA 10 decreased activity was evident during both tasks. Moreover, these effects within lateral and medial BA 10 were greater for intention retrieval than cue identification (see also Burgess et al. 2001; Okuda et al. 1998).

It is difficult to find much discussion in the literature on planning and prospective memory concerning the processes of future-event simulation, but we think that there may be points of connection at both the cognitive and neural levels. At the cognitive level, one can ask whether the kinds of episodic simulation processes considered here are relevant or important for understanding how people remember to carry out future actions. For example, when formulating the intention to pick up milk and butter on the way home from work, is it necessary or useful to imagine carrying out the action, or to mentally simulate the context in which the action will occur? Similarly, does the formulation of more complex plans benefit from simulating alternative scenarios? Some evidence suggests affirmative answers to these questions.

Marsh et al. (2006) reported data suggesting that prospective memory may indeed benefit from processes that would appear to involve episodic simulation. They focused on the question of whether holding an intention to perform a future action results in a cost to other activities during the time period over which the intention is held. If holding intentions interferes with other tasks, then the cost of engaging in prospective activities in everyday life could be prohibitively high. In two experiments investigating event-based and time-based prospective memory, Marsh et al. reported that associating an intention with a specific future context significantly reduced interference with carrying out other tasks during the interval when subjects held the intention, prior to executing the target action. The act of associating an intention with a specific future context can be viewed as a type of episodic simulation, perhaps related to the kinds of simulation processes discussed earlier. If so, then the act of associating an intention with a specific future context might well recruit some or all regions in the core network associated with future-event simulation.

These processes bear a close resemblance to what Gollwitzer (1999) has termed "implementation intentions": plans that link an intention with a specific anticipated situation in which the plan is to be executed. Gollwitzer (1999, p. 494) contrasted implementation intentions ("When situation *x* arises, I will perform response *y*!") with goal intentions ("I intend to reach *x*!"). People form implementation intentions by imagining and rehearsing a plan with respect to the specific future context in which they will execute it. Forming implementation intentions can increase significantly the chances of carrying out an intention or plan. For example, Orbell et al. (1997) asked some women who had the goal of performing a breast self-examination within the next month to imagine exactly when and where they would want to perform the exam. All of the women who formed these implementation intentions reported later that they indeed carried out the exam. By contrast, only half the women who had strong intentions to perform the exam, but were not asked to form additional implementation intentions, later performed the exam. More recent research shows that there are conditions in which older adults can benefit from forming implementation intentions (Chasteen et al. 2001). Older adults who envisaged themselves performing a prospective memory task (writing the day of the week on sheets they would be receiving) were twice as likely to do so as older adults who were asked to perform the same task but did not form this implementation intention.

Implementation intentions likely aid performance by linking an intention to a context-specific mental representation of a future situation that can later cue the intention (see also Seifert & Patalano 2001 for related work). Further study of implementation intentions could represent an informative intersection between episodic simulation processes on the one hand and the formation of intentions and plans on the other.

Neuroimaging research on intentional processing and prospective memory can also inform work on future-event simulation given that there are points of

overlap among the regions activated during simulation and prospective memory. Notable among these regions is frontopolar region (BA 10), which as reviewed earlier has shown preferential activation when people simulate future events (Addis et al. 2007; Okuda et al. 2003), and also during prospective memory tasks (Burgess et al. 2001; Okuda et al. 2003; Simons et al. 2006). Such findings encourage further research that examines whether and to what extent frontopolar regions are specifically related to the prospective aspects of event simulation.

Prediction and Simulation

Predictions are a key component of many kinds of future-related thinking (Hawkins & Blakesee 2005). Predictions about the future may occur at a variety of different time scales and for different purposes. When entering a novel context, such as an office, park, or museum, people use past experiences and associations to generate predictions about what kinds of objects and events are likely to be encountered next (e.g., Bar 2007). When making major life decisions, such as where to accept a job or whom to marry, or more minor ones such as where to spend a vacation or eat dessert, people try to generate predictions about their likely future happiness (Gilbert 2006). Simulations of the future may serve as the basis for many kinds of predictions, and their properties can help to understand why predictions about the future are often erroneous (Gilbert & Wilson 2007).

As Gilbert and Wilson (2007) noted, a key to understanding prediction errors is that future simulations are often based on memories, which are themselves prone to various kinds of inaccuracies. Supporting this idea, Morewedge et al. (2005) found that people often make predictions of their future happiness based on atypical past experiences that are highly memorable to them. However, these atypical experiences do not accurately predict what is likely to occur in the future, thereby resulting in prediction errors. Another example that frequently impacts everyday behavior concerns the fact that individuals often underestimate how long it will take them to complete a task in the future. Roy et al. (2005) summarized evidence indicating that predictions about future task duration are often based on memories of past event duration, which are themselves underestimates of the actual duration. If one mistakenly remembers, for instance, that serving as a grant reviewer took a few hours rather than an entire day, then one may be unpleasantly surprised to discover that a new review cannot be completed during the hours one predicted would be sufficient to complete the task.

Summarizing a broad range of studies, Gilbert and Wilson (2007) distinguished among four properties of simulations that reflect the influence of memory and are likely to contribute to prediction errors: simulations are 1) *unrepresentative*, often capturing the most salient but not the most likely elements of an experience; 2) *essentialized*, omitting some nonessential details that can impact future happiness; 3) *abbreviated*, often overemphasizing the initial part of an event; and 4) *decontextualized*, ignoring aspects of a future context that affect the experience of an event.

Gilbert and Wilson (2007) summarized research from social and cognitive psychology that provides evidence that each of the four key properties of future-event simulations can impact the predictions individuals make about the future happiness or likelihood of engaging in future behaviors. These findings dovetail nicely with the cognitive neuroscience evidence reviewed here, inasmuch as both point to an intimate link between the processes subserving episodic memory and future-event simulation. Nonetheless, the link between simulation and prediction has not yet been made empirically at a brain-systems level. A number of neuroimaging studies using conditioning procedures or decision-making paradigms have examined the brain systems that are involved in generation of signals related to prediction of future reward or punishment, with several studies highlighting a key role for specific regions within the striatum (e.g., Knutson et al. 2000; Seymour et al. 2007; Yacubian et al. 2006). Such findings, coupled with the previously mentioned findings on simulation-based prediction errors, led Gilbert and Wilson (2007) to conceive of future predictions in terms of an interaction between cortically driven simulations and subcortical affective responses to those simulations. These kinds of ideas suggest that neuroimaging and neuropsychological studies of the link between simulation and prediction constitute a promising area for research.

Concluding Comments

Episodic simulation of future events has emerged only recently as a topic of intense interest in cognitive neuroscience, but we hope that we have shown in this article that the issue fits into a broader landscape of research in multiple disciplines. We view the issue as fundamental with respect to both theoretical and applied concerns. On the theoretical side, the study of future-event simulation represents the

intersection of memory processes with those involved in imagination, planning, and prediction. Further study of the issue therefore promises to both broaden and deepen our understanding of the nature and function of memory. As we and others have argued, since planning for the future is a task of paramount adaptive importance, it makes sense to conceive of the brain as a fundamentally prospective organ that is designed to use information from the past and present to generate predictions about the future (e.g., Bar 2007; Buckner & Carroll 2007; Gilbert 2006; Hawkins & Blakesee 2005; Schacter & Addis 2007b; Schacter et al. 2007). Such a perspective encourages us to view memory as a key component of the prospective brain that helps to generate simulations of possible future events that contribute to the formation of plans and predictions. Such a perspective calls for a shift not only in conceptual emphasis, but also a change in methodology. Rather than focusing predominantly on assessing memory with tasks that query the past, greater emphasis should be placed on the development of tasks that capture how memory is used to simulate, plan, and predict the future.

On the applied side, future thinking is crucial to understanding well-being (e.g., Gilbert 2006; Taylor et al. 1998), achievement and goal attainment (e.g., Ajzen 1991; Aspinwall 2005), aging (e.g., Addis et al. in press; Carstensen et al. 1999; Einstein & McDaniel 1990), optimism (Schacter & Addis 2007c; Sharot et al. 2007), and various clinical conditions discussed earlier (e.g., MacLeod et al. 1997; Mesulam 2002). However, despite some progress in the analysis of cognitive and social aspects of these phenomena, our understanding of the neural correlates and basis of the relevant prospective processes is exceedingly modest. Advances in our understanding of the cognitive neuroscience of future-event simulation are thus likely to have implications for addressing a wide array of issues that are essential to everyday life.

Conflict of Interest

The authors declare no conflicts of interest.

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