Adaptive constructive processes and the future of memory

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Abstract

Memory serves critical functions in everyday life, but is also prone to error. This article examines *adaptive constructive processes*, which play a functional role in memory and cognition but can also produce distortions, errors, or illusions. The article describes several types of memory errors that are produced by adaptive constructive processes, and focuses in particular on the process of imagining or simulating events that might occur in one's personal future. Simulating future events relies on many of the same cognitive and neural processes as remembering past events, which may help to explain why imagination and memory can be easily confused. The article considers both pitfalls and adaptive aspects of future event simulation in the context of research on planning, prediction, problem solving, mind-wandering, prospective and retrospective memory, coping and positivity bias, and the interconnected set of brain regions known as the default network.

In 1932, Sir Frederic Bartlett published his landmark volume, *Remembering: A Study in Experimental and Social Psychology*, which drew on evidence of memory distortions to refute the idea that remembering is a literal or exact reproduction of the past. Bartlett (1932) argued instead that remembering "is an imaginative reconstruction or construction (p. 213)" that depends heavily on the operation of a schema, a concept that he borrowed from the British neurologist Henry Head. Bartlett defined a schema as "an active organisation of past reactions, or of past experiences, which must always be supposed to be operating in any well-adapted organic response (1932, p. 201)". He further emphasized the importance of "the organism's capacity to turn round upon its own 'schemata' (p. 213)" during acts of remembering.

The somewhat opaque idea of an organism "turning round upon its own schemata" became sufficiently controversial that Bartlett later tried to clarify the concept in some unpublished notes that have been made available by the Sir Frederic Bartlett Archives at the University of Cambridge (http://www.ppsis.cam.ac.uk/bartlett/NotesOnRemembering.htm). "There is probably no other phrase in *Remembering* that has received as much attention as the expression 'turning round on one's own schemata'" wrote Bartlett. He went on to explain that "turning round" refers to cognitive activities that occur "whenever remembering demands more than the production of a fully learned response" – that is, strategic, voluntary, and constructive activities that are required to respond to a current environmental demand when automatic, learned responses are not elicited. Bartlett argued further that such activities are of great functional importance: "when some current situation demands an adaptive reaction, selection from, or reconstruction of, the organised past must be effected." Despite the adaptive value of this constructive activity, however, "turning round" also has a downside, often resulting in "rationalisation, condensation, very often in a considerable rearrangement of temporal relations, in invention and in general in an exercise of

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constructive imagination to serve whatever are the operating interests at the time at which the turning round takes place."

Adaptive Constructive Processes and Memory Distortion

Bartlett's elaboration of what he meant by "turning round" on one's own schemata reveals an important property of human memory: some processes that contribute to adaptive responding also result in error. In this article, I call them *adaptive constructive processes*, which I define as *processes that play a functional role in memory and cognition but produce distortions, errors, or illusions as a consequence of doing so*. Adaptive constructive processes are not uniquely characteristic of memory. For example, in one of their classic papers on judgment and decision making, Tversky and Kahneman (1974, p. 1124) observed that the heuristics people use when making judgments about the likelihood of uncertain events "are quite useful, but sometimes they lead to severe and systematic errors", thus falling under the rubric of adaptive constructive processes. Students of perception have long argued that visual illusions result from the operation of constructive processes that contribute to the efficient functioning of the visual system (e.g., Gregory & Gombrich, 1973; Roediger, 1996).

Although the idea that memory distortions sometimes reflect the operation of adaptive processes can be traced to Bartlett's (1932) work, and has been embraced by other researchers from time-to-time (e.g., Brainerd & Reyna, 2005; Howe, 2011; Howe, Garner, Charlesworth, & Knott, 2011; Neisser, 1967; Newman & Lindsay, 2009; Schacter, 1999, 2001), in general memory distortions have been viewed as indications of defects or flaws in memory. Consistent with this view, there is evidence that increased incidence of memory distortions is associated with various indicators of suboptimal processing. For example, people who are especially prone to disruptions in consciousness or dissociative experiences have also shown increased rates of susceptibility to various kinds of memory distortions (e.g., Clancy, Schacter, McNally, & Pitman, 2000). More recent studies have linked memory distortion to low intelligence (Zhu et al., 2010) and also to symptoms of post-traumatic stress disorder (Goodman et al., 2011).

Such findings may appear to cast doubt on the adaptive perspective. However, Scott Guerin, Peggy St. Jacques and I (Schacter, Guerin, & St. Jacques, 2011) recently marshaled emerging evidence in favor of the view that some memory distortions do indeed reflect the operation of what I call here adaptive constructive processes (note that I use the term "adaptive" in this article to refer to a beneficial characteristic of an organism, and make no claim about the evolutionary origins of adaptive constructive processes; for discussion of this issue, see McKay & Dennett, 2009; Schacter, 2001; Schacter, Guerin, & St. Jacques, 2011). In our review, we focused on three memory distortions that we believe reflect the operation of such processes: 1) post-event misinformation, 2) gist-based and associative memory errors, and 3) imagination inflation. In the present article, I briefly summarize arguments concerning adaptive aspects of the first two kinds of memory distortions, and then elaborate on the adaptive constructive processes associated with the third.

The misinformation effect pioneered by Loftus and colleagues (for review, see Loftus, 2005) occurs when misleading information presented after an event results in distorted memory for the original event. Though misinformation-based memory errors have important practical consequences (Loftus, 2005), Schacter, Guerin, and St. Jacques (2011) suggested that they can be viewed as a consequence of adaptive updating processes that are crucial for the operation of a dynamic memory system that flexibly incorporates relevant new information (for recent evidence and related ideas, see Edelson, Sharot, Dolan, & Dudai, 2011; Hardt, Einarsson, & Nader, 2010; St. Jacques & Schacter, in press).

Gist-based memory errors occur when people falsely remember a novel item that is similar to an item that they encountered previously, making their memory decision based on the gist of what happened (Brainerd & Reyna, 2005; Koustaal & Schacter, 1997). Associative memory errors occur when people falsely remember a novel item that is associated with previously studied items, as in the well known Deese/Roediger-McDermott or "DRM" memory illusion, where presentation of a series of words (e.g., *candy, sour, sugar, bitter, good, taste, tooth, nice, honey, soda, chocolate, heart, cake, eat, pie*) that are all associated to a nonpresented "critical lure" word (e.g., *sweet*) results in a high level of false recall or recognition of the critical lure on a later memory test (Deese, 1959; Roediger & McDermott, 1995; for review, see Gallo, 2010). Such responses are rightly classified as memory distortions – people claim to remember items that they did not study – but these errors also reflect retention of useful information concerning the general themes or meanings that participants did encounter. Retention of such information can facilitate generalization and abstraction (e.g., Brainerd & Reyna, 2005; McClelland, 1995; Schacter, 1999, 2001) and in that sense can be considered adaptive. Recent evidence links associative false memories with creativity. Dewhurst, Thorley, Hammond, and Ormerod (2011) showed that susceptibility to DRM false recognition is predicted by performance on a remote associates task, which measures convergent thinking – a component of creativity that taps an individual's ability to generate broad and numerous associations, and can thus be considered an adaptive cognitive process (for related evidence, see Howe et al., 2011).

Additional evidence consistent with an adaptive interpretation of gist-based and associative memory distortions comes from neuroimaging studies that have documented that a) many of the same brain regions are active during both associative/gist-based false recognition and true or accurate recognition, and b) regions that are active when people engage in semantic elaboration during encoding, which serves the adaptive function of promoting long-term retention, support both subsequent true and false recognition (for discussion, see Schacter, Guerin, & St. Jacques 2011; Schacter & Slotnick, 2004). Thus, both cognitive and neuroimaging evidence supports an adaptive interpretation of gist-based and associative memory errors.

Imagination Inflation and the Simulation of Future Events

The third kind of memory distortion that Schacter, Guerin, and St. Jacques (2011) discussed within an adaptive framework is known as imagination inflation: imagining events can lead to false memories that the event actually occurred (e.g., Garry, Manning, Loftus, & Sherman, 1996; Loftus, 2003). Imagination inflation is typically viewed as a consequence of a failure in source monitoring operations that allow us to distinguish between events that actually happened and events we only imagined (e.g., Johnson, Hashtroudi, & Lindsay, 1993). There is little doubt that source monitoring failure does play a key role in imagination inflation. Arguing from an adaptive perspective, however, we suggested that imagination inflation also results in part from the role of a constructive memory system in imagining or simulating future events. The capacity to simulate experiences that might occur in one's personal future is potentially adaptive because it allows individuals to mentally "try out" different versions of how an event might play out (Buckner & Carroll, 2007; Ingvar, 1979; Gilbert & Wilson, 2007; Schacter & Addis, 2007; Suddendorf & Corballis, 2007; Tulving, 2005). During the past few years, research in my lab and others has documented striking similarities between remembering the past and imagining the future (for reviews, see Schacter, Addis, & Buckner, 2007, 2008; Szpunar, 2010). For example, neuroimaging studies have revealed extensive overlap in the neural processes that are engaged when people remember past events and imagine future events or novel scenes (e.g., Addis, Wong, & Schacter, 2007; Addis, Pan, Vu, Laiser, & Schacter, 2009; Hassabis, Kumaran, & Maguire, 2007; Okuda et al., 2003; Spreng & Grady, 2010; Szpunar, Watson, &

McDermott, 2007). Similarly, behavioral studies have documented striking similarities in the corresponding cognitive processes associated with remembering the past and imagining the future (e.g., D'Argembeau & Van der Linden, 2006; D'Argembeau & Mathy, 2011; Szpunar & McDermott, 2008). Moreover, deficits in remembering the past are often accompanied by parallel deficits in imagining the future in various populations, including several patients with amnesia (for review, see Addis & Schacter, 2012), older adults and patients with Alzheimer's disease (for review, see Schacter, Gaesser, & Addis, 2011), and patients with depression (Williams et al., 1996) or schizophrenia (D'Argembeau, Raffard, & Van der Linden, 2008). These similarities can help to explain why memory and imagination are easily confused: they share common neural and cognitive underpinnings (see also Johnson et al., 1993).

Even more important from the perspective of adaptive constructive processes, Donna Addis and I have argued that these observations provide clues about the adaptive functions of a constructive memory system. Specifically, Schacter and Addis (2007) have put forward the *constructive episodic simulation hypothesis*, which holds that past and future events draw on similar information stored in memory (episodic memory in particular) and rely on similar underlying processes. Episodic memory, in turn, supports the construction of future events by extracting and recombining stored information into a simulation of a novel event. Schacter and Addis (2007) claimed that such a system is adaptive because it enables past information to be used flexibly in simulating alternative future scenarios without engaging in actual behaviors, but it comes at a cost of vulnerability to errors and distortions that result from mistakenly combining elements of imagination and memory (for related ideas, see Suddendorf & Corballis, 2007).

In the remainder of this article, I will discuss further the process of imagining or simulating future events from the perspective of adaptive constructive processes, considering both the vulnerabilities and adaptive functions of future event simulation.

Future Event Simulation: Some Pitfalls

A central tenet of the constructive episodic simulation hypothesis (Schacter & Addis, 2007) and related perspectives (Suddendorf & Corballis, 2007) is that the ability to flexibly recombine elements of past experience into simulations of novel future events is an adaptive process, sufficiently beneficial to the organism that it is worth the concomitant cost in memory errors that result from occasionally mistakenly combining those elements. From this perspective, simulating future events ought to confer discernable advantages on the organism.

Mispredicting the Future and the Planning Fallacy

One problem with this view, however, is that considerable research indicates that future event simulations are themselves error prone. Consider, for example, predictions that people make about their future happiness and related hedonic experiences. People frequently overestimate or underestimate their future happiness across a range of situations, which Gilbert and Wilson (2007) attribute to the properties of the simulations that people use as a basis for predictions. Specifically, Gilbert and Wilson (2007) point out that simulations of future experiences are frequently *unrepresentative*, often capturing the most salient but not the most likely elements of an experience; *essentialized*, omitting some nonessential details that can impact future happiness; *abbreviated*, often overemphasizing the initial part of an event; and *decontextualized*, ignoring aspects of a future context that affect the experience of an event.

Similarly, Dunning (2007) has highlighted the limitations of simulation (what Dunning refers to as "scenario building") in the context of planning for the future. For example, the well-known planning fallacy (Buehler, Griffin, & Peetz, 2010; Kahneman & Tversky, 1979) occurs when people tend to underestimate the time that will be needed to complete a future task, ranging from an undergraduate senior thesis to income tax returns and holiday shopping (for review, see Buehler et al., 2010). Dunning (2007) summarizes evidence that people depend on simulations of how they will go about completing a task that are incomplete in critical respects and therefore contribute to the occurrence of the planning fallacy. Dunning (2007) argues that simulations can result in poor planning outcomes for a variety of reasons, including that people often rely too heavily on a few abstract features of the simulated scenarios, neglect alternative outcomes to the ones they simulate, highlight positive aspects of simulated scenarios while overlooking their negative aspects, and fail to take into account the reliability and validity of the information that is included in simulations (for related ideas, see Buehler et al., 2010; Kahneman & Tversky, 1979).

While these observations clearly indicate that there are situations in which simulations can lead us astray (see Mathieu & Gosling, 2012, for circumstances in which predictions show relative accuracy), such errors may reflect, at least in part, the tight connection between memory and simulation (Gilbert & Wilson, 2007; Schacter et al., 2008). Considering the planning fallacy, for example, Roy, Christenfeld, and McKenzie (2005) discuss evidence that predictions about future task duration tend to be based on memories of past event duration. Critically, these memories sometimes underestimate the actual duration. If one mistakenly remembers, for instance, that completing one's income taxes took an hour rather than an entire afternoon, then one may be unpleasantly surprised to discover that the task cannot be completed during the time one predicted would be sufficient to complete it. Morewedge, Gilbert, and Wilson (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, and thus can lead to prediction errors.

Instability of Future Simulations

In addition to this evidence that future simulations are error prone, other studies indicate that the act of imagining a future event can alter the subjective likelihood that an event will occur, even though there is no corresponding change in objective circumstances that would warrant a change in subjective perception. This effect was first demonstrated when Carroll (1978) showed that participants who imagined that Jimmy Carter would win the 1976 presidential election were more likely to predict that Carter would win the election over Gerald Ford, whereas participants who imagined that Ford would win were more likely to predict a Ford victory. Subsequent studies extended this basic finding to other kinds of events, such as imagining winning a contest or contracting a disease (for review, see Koehler, 1991).

More recently, Karl Szpunar and I showed that repeatedly imagining specific, everyday future experiences – interpersonal interactions comprised of familiar people, locations, and objects – increases the subjective plausibility that the simulated experiences would actually occur (Szpunar & Schacter, in press). However, this increased plausibility was observed only for positive or negative emotional events (not for neutral events; see Szpunar and Schacter, in press, for discussion of possible cognitive mechanisms). While it is difficult to know whether an initial simulation or a repeated simulation provides a more accurate assessment of future likelihood or plausibility, these experiments illustrate that a critical aspect of simulating an emotionally arousing future event – its subjective plausibility – can change significantly even when there are no changes in objective circumstances that correspond to the changes in subjective plausibility. These and earlier findings raise the

possibility that instability in future simulations could undermine their usefulness as a guide to predicting or planning the future.

The Default Network: An Antagonist of Goal-Directed Cognition?

As noted earlier, neuroimaging studies have shown that remembering the past and imagining the future engage many of the same brain regions. This common core network (Schacter et al., 2007), also known as the *default network* (e.g., Raichle et al., 2001; for review, see Buckner, Andrews-Hanna, & Schacter, 2008), includes medial prefrontal cortex, retrosplenial cortex, posterior cingulate, medial temporal lobe, and lateral temporal and lateral parietal cortices. The default network was initially identified in neuroimaging studies as increased activity in the foregoing brain regions during passive rest states compared with conditions in which individuals performed attention demanding, goal-directed cognitive tasks (Raichle et al., 2001; Shulman et al., 1997). In other words, default network activity showed a relative decrease during goal-directed cognitive tasks compared with passive rest states. These passive rest states were not themselves targets of experimental investigation, but instead were included as control or comparison conditions for the goal-directed cognitive tasks of interest (Buckner et al., 2008). In light of more recent research showing default network activity when people remember the past or imagine the future, it seems likely that during passive rest states, participants' thoughts drifted off to past experiences or possible future experiences. Most critical for the present purposes, the observation that the default network was less active during goal-directed cognitive tasks than during passive rest led a number of subsequent investigators to propose that the default network does not contribute to goal-directed cognitive processing and that its activity might even be antithetical to goal-directed cognition (for discussion, see Spreng, Stevens, Chamberlain, Gilmore, & Schacter, 2010).

Consistent with these observations, Mason et al. (2007) reported fMRI evidence that activation in default network regions can indicate the occurrence of mind-wandering during task performance: default network activity increased when participants performed well-practiced, goal-directed working memory tasks that were characterized by frequent incidents of mind-wandering, compared with novel task conditions in which mind-wandering occurred less frequently. Moreover, increased activity in several default network regions during practiced (versus novel) tasks was positively correlated with self-reported tendencies for mind-wandering.

These observations do not directly question the adaptive value of future simulations, and indeed hypotheses have been advanced concerning possible adaptive functions of the default network (see Buckner et al., 2008). Nonetheless, since future simulations are thought to be important for goal-directed tasks, the foregoing considerations may raise questions concerning their utility because they indicate that the brain network most closely linked with future simulation is also associated with mind-wandering activity that increases when individuals stray from performing a goal-directed task. Moreover, in most studies that have linked default network activity with simulation of future experiences, the simulated future events are not linked to formulating a plan, solving a future problem, or any other kind of goal-directed cognitive activity. Instead, they represent imaginary scenes or scenarios that might or might not occur to the individual within a particular future time frame (e.g., Addis et al., 2007; Addis, Pan, et al., 2009; Hassabis et al., 2007; Okuda et al., 2003; Spreng & Grady, 2010; Szpunar et al., 2007). Therefore, these studies do not indicate whether the default network can contribute to goal-directed cognitive activity.

Future Event Simulation: The Case for Adaptive Function

The evidence considered in the previous section indicates that future simulations can be error prone, unstable, and associated with a brain network that supports off-task mental activity, thereby casting doubt on the adaptive value of the ability to simulate future events. Let us now consider evidence that supports an adaptive role for future simulations.

The Default Network Can Support Goal-Directed Cognition

In light of evidence linking default network activity to off-task mind-wandering, it is important that recent studies show that, contrary to early ideas, the default network can indeed support certain kinds of goal-directed cognition (e.g., Andrews-Hanna, Reidler, Sepulcre, Poulin, & Buckner, 2010). Consider a recent fMRI study from my lab led by Nathan Spreng (Spreng et al., 2010) that examined brain activity associated with two forms of planning. *Visuospatial planning* was assessed by the well-established Tower of London task (e.g., Shallice, 1982), where participants are shown a configuration of discs on a vertical rod in an initial position. Participants attempt to determine the minimum number of moves needed to match the configuration of discs shown in a goal position on another vertical rod, while following rules that constrain the kinds of moves they can make. *Autobiographical planning* was assessed by a novel task that was visually matched to the Tower of London task but required participants to devise plans in order to meet specific goals in their personal futures. For example, *freedom from debt* constituted one of the goals in the autobiographical planning task. Participants viewed the goal and then saw two steps they could take toward achieving that goal (good job and save money) as well as an obstacle they needed to overcome in order to achieve the goal (have fun). They were instructed to integrate the steps and obstacles into a cohesive personal plan that would allow them to achieve the goal.

The fMRI results showed clearly that goal-directed autobiographical planning engaged the default network. Importantly, during the autobiographical planning task, activity in the default network coupled with a distinct network, known as the frontoparietal control network (e.g., Vincent, Kahn, Snyder, Raichle, & Buckner, 2008) that has been linked to executive processing. By contrast, visuospatial planning during the Tower of London task engaged a third network – the dorsal attention network, which is known to increase its activity when attention to the external environment is required (e.g., Corbetta & Shulman, 2002) – that also coupled with the frontoparietal control network. These results suggest that the default network can support goal-directed cognition of a particular kind – autobiographical planning – and that it does so by working with the frontoparietal control network, which appears capable of flexibly coupling with distinct networks depending on task demands (for further discussion and additional data with older adults, see Spreng & Schacter, in press).

A related study led by Kathy Gerlach provides additional evidence on this point (Gerlach, Spreng, Gilmore, and Schacter, 2011). Gerlach et al. (2011) conducted fMRI scans while participants performed a goal-directed task in which they generated mental simulations in order to solve specific problems that arose in imaginary scenarios. For example, participants were asked to imagine being left alone in a friend's dorm room, and trying on their friend's ring, which they could not remove. They were then given the cue word "soap" to help them imagine a solution to the problem. Gerlach et al. (2011) found that, relative to a control task that involved semantic processing but not mental simulation, the problem-solving task engaged several key regions within the default network, including medial prefrontal cortex and posterior cingulate, as well as a region of dorsolateral prefrontal cortex that has been linked with executive processing. Converging nicely with these results and those of Spreng et al. (2010), Ellamil, Dobson, Beeman, and Christoff (2012) examined the generation and

evaluation of creative ideas, using a fMRI-compatible tablet that allowed participants to draw and write ideas during the fMRI scan. Ellamil and colleagues reported that during creative generation, the medial temporal lobes showed increased activity; during creative evaluation, default network regions coupled with executive regions, including dorsolateral prefrontal cortex.

The foregoing evidence that the default network can support certain kinds of goal-directed activity also fits well with recent cognitive evidence concerning the adaptive value of mind-wandering. Contrary to the prevalent idea that mind-wandering represents a kind of cognitive failure, explorations of the content of mind-wandering by Baird, Smallwood, and Schooler (2011) reveal that people typically focus on the future and engage in extensive autobiographical planning during mind-wandering episodes (for similar findings, see Stawarczyk, Majerus, Maj, Van der Linden, & D'Argembeau, 2012). Critically, individuals with high working memory capacity, a measure of executive processing skills, engaged in more future-oriented thought during mind-wandering than did individuals with low working memory capacity. These findings further support the idea that mind-wandering serves adaptive functions and are consistent with fMRI observations that both default network and executive regions are active during mind-wandering (Christoff, Gordon, Smallwood, Smith, & Schooler 2009).

Future Simulations Can Benefit Goal-Directed Cognition

The preceding evidence shows clearly that the default network, which underpins future event simulation, supports internally-directed cognitive activities that are associated with adaptive, goal-directed processing. Consistent with this view, behavioral evidence also links future simulations with planning, problem-solving, and related forms of goal-directed processing. Taylor, Pham, Rifkin, and Armor (1998) pointed out that mental simulations are well-suited to support planning and problem solving activity because they: 1) include specific information about people, places, and social roles that can be helpful to generating problem solutions; 2) frequently contain a causal structure that resembles an actual situation, and 3) may provide access to information that would be otherwise overlooked but is critical to planning. Studies by Taylor and her colleagues have shown that simulations can help college students to plan and prepare for upcoming exams when their simulations include specific information about the steps they need to take to prepare for the exam (see Taylor et al., 1998, for review). More recent evidence indicates that simulations are useful when attempting to solve open-ended social problems, where different possible solutions to a problem need to be explored and evaluated. Sheldon, McAndrews, and Moscovitch (2011) reported that older adults, who tend to provide less detailed autobiographical memories and simulations of future events than younger adults (e.g., Addis, Wong, & Schacter, 2008; for review, see Schacter, Gaesser, & Addis, 2011) also generated fewer relevant steps than controls when simulating solutions to ill-defined problems, suggesting that without an ability to generate detailed simulations, the effectiveness of problem solving is reduced. The tight linkage between simulations and goal-directed processing has been emphasized by D'Argembeau and Mathy (2011), who reported that when people simulated future events, cuing participants with their personal goals facilitated access to episodic details. These observations led the authors to conclude that: "knowledge about personal goals plays an important role in the construction of episodic future thoughts (p. 258)".

Future simulations can also have beneficial consequences on decisions about the future as well as the likelihood of carrying out future actions. Consider the phenomenon of temporal discounting: people tend to devalue a reward according to the extent of delay until the reward is delivered (Green & Myerson, 2004). Boyer (2008) argued that a key adaptive function of future simulation is to allow individuals to represent emotional aspects of distant future rewards in a way that overcomes temporal discounting, producing less impulsive and

more farsighted decisions. Consistent with this view, recent research has shown that when people imagine experiencing a reward in the future, they show an increased tendency to favor rewards that produce greater long-term payoffs, thereby countering the normal tendency to devalue delayed rewards (Benoit, Gilbert, & Burgess, 2011; Peters & Büchel, 2010). For example, Benoit et al. (2011) instructed participants to imagine specific episodes of spending money in a pub at particular times in the future. Compared with a control condition in which they estimated what the money would purchase, simulating the future rewards biased participants toward accepting a larger delayed reward (e.g., $70 in 90 days) rather than a smaller immediate reward (e.g., $50 now). Benoit et al. (2011) scanned participants during this procedure, and showed that effects of episodic simulation on temporal discounting are associated with increased coupling between activity in the hippocampus and prefrontal regions involved in reward representation (see also, Peters & Büchel, 2010).

Future Simulations Can Enhance Prospective and Retrospective Memory

Simulating future events can also increase *prospective memory* or the probability of carrying out intended actions in the future. This point has been demonstrated in studies of *implementation intentions*: plans that link an intention with a specific anticipated situation in which the plan is to be executed (Gollwitzer, 1999). Implementation intentions benefit subsequent prospective memory performance by increasing the probability that when the future context is encountered, the intended action is triggered (e.g., Chasteen, Park, & Schwarz, 2001), and recent evidence indicates that mental simulations contribute significantly to the effectiveness of implementation intentions (Brewer & Marsh, 2010; Papies, Aarts, & De Vries, 2009). These findings documenting beneficial effects of simulations on prospective memory complement a large research literature demonstrating that imagining carrying out various kinds of skills – ranging from athletic acts to surgical procedures – can produce significant benefits on their later performance (e.g., Arora et al., 2011; Taylor et al., 1998; van Meer & Theunissen, 2009).

Recent evidence indicates that simulating future events can also aid performance on traditional tests of retrospective memory. Several decades ago, Ingvar (1985) argued that "memory of the future" – that is, remembering the contents of simulated future events – constitutes an important adaptive function because remembering what we have planned to do or say in an upcoming episode can increase the effectiveness and efficiency of future behavior. Although little is known about memory for future simulations, recent studies by Klein, Robertson, and Delton (2010, 2011) have shown that constructing simulations of possible future events constitutes a highly effective form of memory encoding. Their studies addressed research by Nairne and colleagues that had shown that encoding information with respect to its potential survival value results in greater subsequent recall and recognition than a variety of well-established encoding procedures (for review, see Nairne, 2010). Klein and colleagues demonstrated that much or possibly all of the benefit of such "survival encoding" is attributable to planning processes. For example, when participants imagine scenarios in which they are stranded in grasslands without food, and encode a list of words with respect to their survival relevance, survival scenarios that involve planning produce superior subsequent memory to survival scenarios that do not involve planning; superior recall is also observed for scenarios that involve planning but not survival (e.g., planning a dinner party; Klein et al., 2011). This encoding benefit is specific to future scenarios: it is not observed when people encode information by calling up past scenarios or imagining "atemporal" scenarios (Klein et al., 2010).

Although next to nothing is known about the neural processes that support encoding of future scenarios, a recent fMRI study by Martin, Schacter, Corballis, and Addis (2011) indicates that the hippocampus plays an important role. During fMRI scanning, participants

imagined future scenarios comprised of people, locations, and objects that were extracted from autobiographical memories provided by each participant prior to the scan, and had been randomly recombined by the experimenters. Memory for simulations was tested shortly after the scan by providing two elements of the simulated episode (e.g., person and object) and probing recall of the third element (e.g., location); a simulation was classified as "remembered" when participants recalled the third element correctly and as "forgotten" when they did not. Greater hippocampal activity was observed during construction of subsequently remembered than forgotten simulations, even when controlling for the amount of detail associated with each simulation (for discussion of related findings, see Addis & Schacter, 2012; Buckner, 2010; Maguire, Vargha-Khadem, & Hassabis, 2010; Schacter & Addis, 2009; Squire et al., 2010).

Future Simulations Can Enhance Psychological Well-Being

The adaptive value of future simulations is also supported by research that has established that they can contribute to psychological well-being. For example, college students who simulated details and emotions associated with an ongoing stressful event reported using more effective coping strategies one week later compared with control groups (Taylor et al., 1998). Similarly, in a study where women with first-time pregnancies were asked to simulate going into labor and arriving at the hospital on-time, more detailed and coherent simulations were correlated with increased subjective probability of a positive outcome and decreased amounts of worry related to the future event (Brown, Macleod, Tata, & Goddard, 2002).

These findings are of interest with respect to the positivity bias that frequently characterizes future thinking (Sharot, 2011), because such biases have been linked to a number of adaptive processes, including emotional well-being, forming social bonds, productivity at work, and coping with stress effectively (e.g., Taylor, 1989). Further, recent research has shown that positivity biases are observed when people remember simulations of positive, negative, and neutral future events: details associated with negative simulations were more difficult to remember over time than details associated with positive or neutral simulations, thus promoting recollection of a rosy simulated future (Szpunar, Addis, & Schacter, 2012).

Finally, recent studies have revealed a benefit of future simulations with potentially important social implications: mentally simulating positive encounters with members of an outgroup, including individuals of a different race, age, or sexual orientation, results in more positive attitudes toward, and less stereotyping of, the outgroup represented in the simulated contact (Crisp & Turner, 2009). Simulated contact reduces anxiety associated with outgroup encounters (Crisp & Turner, 2009) and thereby positively impacts psychological well-being.

Concluding Comments

Future event simulation clearly plays a functional role in memory and cognition, but also can produce distortions or errors, and in that sense constitutes a paradigmatic case of an adaptive constructive process. How can we reconcile the contrasting patterns of evidence reviewed in the previous sections? A key point arises from the observation made by such researchers as Gilbert and Wilson (2007) and Dunning (2007) that simulations of future events can result in inaccurate predictions regarding the future, and often provide an inadequate basis for planning, because they are incomplete in various ways. As a result, when a future scenario involves features or properties that are not represented when people imagine that scenario, but are relevant to how they will feel or perform when the scenario actually unfolds, individuals are very likely to be led astray by their incomplete, essentialized, or unrepresentative simulations. By contrast, simulations tend to be useful when they do represent critical features of an upcoming situation.

This point is illustrated nicely by studies from Taylor et al. (1998) referred to earlier. In one study, college students who simulated the specific steps that were important for success on an exam (*process simulation*; e.g., simulating themselves in the act of studying) began studying earlier, spent more time studying, and achieved a higher grade than did students who simulated how good they would feel if they received a high grade (*outcome simulation*). In a related study, students who constructed process simulations for an upcoming project that contained the steps critical to executing the project (e.g., imagining themselves gathering relevant materials and beginning to work on the project) were less prone to the planning fallacy than were students who constructed outcome simulations that did not contain the critical steps (e.g., how pleased they would be with the completed project). In both examples, simulations were useful only when they contained features that were critical to later task execution.

These considerations suggest that our understanding of both the benefits and foibles of future simulations will be improved by attempting to specify the conditions that promote a match or mismatch between the elements of a simulation and critical features of an upcoming event. The simulation elements and event features could entail steps necessary to perform a task or plan for its execution, an unresolved personal problem, or feelings about pleasant or unpleasant personal outcomes. Understanding the factors that promote match or mismatch between simulation elements and event features will, in turn, depend on better understanding how people retrieve and recombine information from memory to represent a future event (Gilbert & Wilson, 2007; Schacter & Addis, 2007; Tulving, 2005). More generally, studying adaptive constructive processes should help to provide a deeper understanding of the functions of memory, in line with the agenda set forth by Bartlett (1932) eighty years ago. Bartlett emphasized not only the constructive nature of memory, but also the functions that memory serves in such diverse processes as interpretation, problem solving, and social cognition. A combined emphasis on constructive and functional processes should broaden our understanding of how memory links the past with the future.

Acknowledgments

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