8 Memory and Imagination: Perspectives on Constructive Episodic Simulation

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Questions concerning the relation between memory and imagination have occupied a prominent place in cognitive psychology and cognitive neuroscience during the past several decades. Johnson and Raye's (1981) reality monitoring framework brought the issue into prominence by portraying the relation as constituting a fundamental problem that must be addressed by any cognitive model. Johnson and Raye's framework provided the inspiration for subsequent cognitive and neuroimaging studies concerning the mnemonic qualities of perceived and imagined events, and the underlying psychological and neural processes that allow us to distinguish between them (for an update, see Simons, Garrison, and Johnson, 2017).

A little more than a decade ago, a related line of research emerged that focused on striking neural and cognitive similarities that occur when people remember past experiences and imagine or simulate future and hypothetical experiences. The foundation of this work was set in the 1980s and 1990s by clinical observations that an amnesic patient with a severe deficit in recalling past experiences also had comparable difficulties imagining future experiences (Tulving, 1985; see also, Klein, Loftus, and Kihlstrom, 2002) and that suicidally depressed patients showed similar reductions in the specificity of autobiographical memories and future imaginings (Williams et al., 1996). Observations that remembering past experiences and imagining future experiences show similar neural correlates (Okuda et al., 2003), phenomenological characteristics (D'Argembeau and van der Linden, 2004) and individual differences (D'Argembeau and van der Linden, 2006) heightened interest in the relation between the two. This growing interest was galvanized by the publication in 2007 of several papers that strengthened the case for a link between remembering and imagining by revealing strong overlap in the brain regions engaged when people remembered past experiences and either imagined future experiences (Addis, Wong, and Schacter, 2007; Szpunar, Watson, and McDermott, 2007) or imagined novel scenes (i.e. *scene construction*: Hassabis, Kumaran, and Maguire, 2007a). This evidence from functional magnetic resonance imaging (fMRI) was complemented by neuropsychological evidence showing that several amnesic patients with medial temporal lobe damage exhibit scene construction deficits (Hassabis et al., 2007b).

Based on these and related observations, Schacter, Addis, and Buckner (2007; see also, Buckner and Carroll, 2007) pointed to the existence of a core neural network,

comprised of medial temporal and frontal lobes, posterior cingulate and retrosplenial cortices, and lateral parietal and temporal areas, that supports both remembering and imagining – a network that overlaps substantially with the well-known default mode network (for review, see Buckner, Andrews-Hanna, and Schacter, 2008; Raichle, 2015). Other papers published in 2007 delineated theoretical implications of this emerging line of research for a variety of issues in psychology and neuroscience, including the nature of constructive memory (Schacter and Addis, 2007a, 2007b) and the evolution of mental time travel (Suddendorf and Corballis, 2007).

Since 2007, there has been a vast amount of research exploring the relation between memory on the one hand and imagination, simulation, and scene construction on the other. This rapidly growing literature has been thoroughly reviewed in a number of publications (e.g. Klein, 2013; Michaelian, 2016; Michaelian, Klein, and Szpunar, 2016; Mullally and Maguire, 2014; Schacter et al., 2012; Schacter, Benoit, and Szpunar, 2017; Szpunar, Spreng, and Schacter, 2014; Ward, 2016).

In the present chapter, we do not seek to provide yet another comprehensive review regarding the relation between memory and imagination. Instead, we provide a more focused theoretical discussion motivated by an idea that we initially advanced in 2007 that we refer to as the *constructive episodic simulation hypothesis* (Schacter and Addis, 2007a, 2007b). This hypothesis focuses on the important role of episodic memory (Tulving, 2002) in generating simulations of imagined future events, which we have referred to as *episodic simulation* (Schacter, Addis, and Buckner, 2008). As stated in our initial formulation of the constructive episodic simulation hypothesis, a key function of episodic memory is to support the construction of imagined future events by allowing the retrieval of information about past experiences and the flexible recombination of elements of past experiences into simulations of possible future scenarios. We suggested that remembering past events and simulating future events draw on similar kinds of information in episodic memory and rely on a number of shared processes, including the capacity for relational processing (i.e. linking together disparate bits of information; Cohen and Eichenbaum, 1993). We further argued that the flexible, constructive nature of episodic memory makes it well suited to supporting simulations of ways in which future experiences might play out: The future is rarely an exact repetition of the past, so it is important that information stored in memory can be accessed flexibly and recombined to form simulations of novel upcoming events that are informed by past experiences. However, we suggested that this same flexible, constructive character of episodic memory can produce memory errors that result from miscombining elements of past experiences or confusing imagined and actual events.

More than a decade has passed since we advanced the constructive episodic simulation hypothesis, and there is now a great deal more pertinent experimental work available. In this chapter, we discuss how the constructive episodic simulation hypothesis has fared during the past decade, and how we think about the hypothesis now compared with the original formulation in 2007. We believe that such discussion can help to bring out a number of key theoretical issues regarding the nature of the cognitive and neural mechanisms that underpin the relation between memory and imagination (for related discussions, see Addis, 2018; Schacter and Madore, 2016).

The chapter consists of four main sections. First, we consider cognitive/behavioral studies that have tested the constructive episodic simulation hypothesis. Second, we discuss some of the cognitive neuroscience research on remembering and imagining published since 2007 that has informed our understanding of the neural underpinnings of the constructive episodic simulation hypothesis. Third, a key idea in our 2007 formulation was that the flexible recombination processes that are critical for constructing episodic simulations of imagined future events can also contribute to memory errors. No direct evidence on this point was available at the time, but over the past few years relevant evidence has emerged that we review here. Fourth, we clarify ways in which the conceptual focus of the constructive episodic simulation hypothesis has changed over the past decade.

Assessing the Constructive Episodic Simulation Hypothesis: Cognitive/Behavioral Evidence

One line of cognitive/behavioral evidence that has generally supported the constructive episodic simulation hypothesis comes from studies showing that various patient populations characterized by episodic memory deficits show similar impairments when asked to imagine future or hypothetical events (for reviews, see Hallford et al., 2018; Schacter, Addis, and Buckner, 2008; Schacter et al., 2012; Ward, 2016). Similarly, individual, cultural, and gender differences in level of detail and specificity for remembered past events are paralleled in imagined future events (e.g. Cao et al., 2018; D'Argembeau and van der Linden, 2006; Palombo et al., 2013; Wang et al., 2011).

A related line of evidence comes from studies of normal aging. Addis, Wong, and Schacter (2008) presented young and older adults with a series of word cues, and instructed them to either remember a past experience or imagine a future experience related to the cue word in as much detail as possible. The resulting transcripts were scored using the Autobiographical Interview (AI) that had been previously developed by Levine et al. (2002). The AI distinguishes between two major kinds of details: *internal* or episodic, including who, what, where, and when information, and *external*, including semantic knowledge, related facts, commentary, or references to other events including general events. Replicating earlier work by Levine et al. (2002), Addis, Wong, and Schacter (2008) found that when remembering past experiences, older adults produced fewer internal and more external details than did young adults. Importantly, Addis, Wong, and Schacter (2008) also documented the same pattern for imagined future events. In a subsequent study, Addis et al. (2010) reported an identical pattern of results when using an *experimental recombination procedure* in which participants initially provide autobiographical memories, comprised of a person, place, and object, and the experimenter then recombines the three elements across memories to generate novel stimuli for imagination trials. In a later session, participants imagine a novel event involving the recombined person, place, and object elements, or remember some of the original episodes. Once again, older adults produced fewer internal and more external details for both remembered

and imagined events than did young adults, and were less able to integrate all three elements together into a coherent episode.

We initially interpreted the striking parallels between episodic memory and simulation in the Addis, Wong, and Schacter (2008) and Addis et al. (2010) studies as direct support for the constructive episodic simulation hypothesis, theorizing that age-related impairments in retrieving and/or recombining episodic details are responsible for the similar age-related reductions in internal details for remembered past and imagined future events. However, the results of a subsequent study by Gaesser et al. (2011) raised questions about this interpretation. Gaesser et al. (2011) provided pictures of complex scenes to young and older adults, and in conditions comparable to earlier studies instructed participants to generate either memories or imagined future events that were related to the cues. Extending previous results, Gaesser et al. (2011) found parallel age-related declines in internal details (and increases in external details) for both past and future events, pointing again toward an age-related decline in episodic retrieval as the common mechanism. Importantly, however, Gaesser et al. (2011) also included a third condition in which participants were asked to simply describe each picture cue in as much detail as possible (internal details for this task were defined as details present in the depicted scene; external details were defined in the same way as on the memory and imagination tasks). If age-related episodic retrieval impairments are entirely responsible for the reduced internal details by older adults in memory and imagination, then no such reduction should be observed for picture description, because the task should not involve any episodic retrieval. However, Gaesser et al. (2011) observed the same pattern of reduced internal details and increased external details on the picture description task as in the memory and imagination tasks.

Because episodic memory should not impact the picture description task, these results challenged our interpretation of parallel age-related declines in memory and imagination as support for the constructive episodic simulation hypothesis. The results suggested instead that non-episodic factors that are common to the memory, imagination, and description tasks may be primarily responsible for the similar effects of aging on the three tasks. These non-episodic factors could include age-related differences in narrative style or increased off-topic speech in older adults (for further discussion, see Abram et al., 2014; Schacter, Gaesser, and Addis, 2013) that would produce decreased internal and increased external details among older adults on memory, imagination, and description tasks. Moreover, these observations raised the possibility that the aforementioned similarities between remembering and imagining documented in other studies might be produced partly or entirely by non-episodic rather than episodic influences.

Distinguishing Between Episodic and Non-Episodic Influences: Episodic Specificity Induction

The foregoing considerations highlight the critical need to distinguish between episodic and non-episodic influences in order to properly evaluate the constructive episodic simulation hypothesis. Madore, Gaesser, and Schacter (2014) attempted to

do so by giving participants brief training in recalling episodic details of a recent experience – an *episodic specificity induction* (ESI) – and examining the downstream effects of such training on subsequent tasks. The ESI is adapted from the Cognitive Interview, which was initially developed as a forensic protocol for increasing retrieval of episodic details of a recent experience from eyewitnesses (Fisher and Geiselman, 1992). The logic of this approach holds that an ESI should increase performance on a subsequent cognitive task only if that task relies on episodic retrieval processes. According to the constructive episodic simulation hypothesis, both remembering past experiences and imagining future experiences in response to picture cues recruit episodic retrieval, and thus should be impacted by a prior ESI, but describing a picture does not involve any episodic retrieval and thus should not be influenced by a prior ESI.

In the study by Madore, Gaesser, and Schacter (2014), participants viewed a brief video of people performing various tasks in a kitchen, and then either received an ESI that directed them to recall the video in as much detail as possible, or a control induction in which they provided their general impressions of the video. Consistent with predictions, Madore, Gaesser, and Schacter (2014) found that following ESI compared with the control induction, both young and old adults produced more internal details during memory and imagination tasks. By contrast, the ESI had no effect on the number of external details on these tasks, or on the number of internal or external details that participants produced on a picture description task (this pattern of results was replicated in a subsequent experiment using a more neutral control induction in which participants simply completed math problems instead of the general impressions control). Madore and Schacter (2016) replicated and extended these results in a young adult sample using words instead of pictures as cues for memory and imagination.

These experiments demonstrate that an episodic retrieval process that is common to remembering past experiences and simulating future experiences can be dissociated from semantic retrieval and narrative description, and therefore supports the constructive episodic simulation hypothesis. More recent studies have extended this approach to other aspects of future simulations, and to related domains in which there are reasons to suppose that episodic retrieval and simulation play an important role in task performance. For example, in studies of social problem-solving, participants perform a *means-end problem-solving* task (MEPS; Platt and Spivack, 1975) in which they are given hypothetical social problems, such as difficulties with friends or handling a situation at work, and attempt to generate means or steps that can solve the problem. Several studies have reported that MEPS performance is positively correlated with the specificity and detail of autobiographical memories in depressed and anxious patients (e.g. Raes et al., 2005) as well as in older adults (Sheldon, McAndrews, and Moscovitch, 2011), suggesting that MEPS performance draws on episodic retrieval and simulation abilities. Consistent with this idea, Madore and Schacter (2014) reported that ESI boosts MEPS performance in young and older adults: Both groups generated more steps that were deemed relevant to solving a social problem, but not more irrelevant steps, after ESI vs. an impressions control induction. Jing, Madore, and Schacter (2016) extended these findings to the domain of personally worrisome future

experiences, and found that ESI also boosted the number of alternative positive outcomes that participants imagined regarding standardized or personal negative future events. McFarland et al. (2017) recently documented similar ESI effects on MEPS, remembering, and imagining in a sample of depressed adults.

A parallel line of research has used ESI to reveal that episodic retrieval contributes to aspects of divergent creative thinking, a form of simulation that is analogous in some respects to imagining future events (Roberts and Addis, 2018). Based on several kinds of evidence suggesting the possibility of such a link (for review, see Beaty et al., 2016), Madore, Addis, and Schacter (2015) administered ESI and control inductions (either impressions or math problems) prior to performance of a standard test of divergent thinking that requires generating novel but appropriate uses of common objects (Alternate Uses Task or AUT), or an object association task (OAT) that requires generation of object characteristics related to a cue object, but places little demand on divergent thinking. Madore, Addis, and Schacter (2015) found that ESI (vs. a control induction) boosted measures of generative output on the AUT (e.g. measures of novel and appropriate object uses such as fluency and flexibility) while having no effect on OAT performance. We replicated this effect in a second experiment that also revealed that ESI had no detectable impact on a measure of convergent thinking, and later extended the main findings to a different divergent thinking task and to an older adult population (Madore, Jing, and Schacter, 2016). The novel uses generated on the AUT following ESI were not rated as any more original than those generated after a control induction; there were simply *more* novel uses of approximately equal originality generated after an ESI than a control induction.

In summary, studies of autobiographical remembering, future imagining, social problem-solving, and divergent thinking using ESI have established a role for episodic retrieval in these tasks, which all involve some type of mental simulation. ESI allows the influence of episodic retrieval to be distinguished from other, non-episodic influences that may be operating in parallel with episodic retrieval on these tasks, and critically, the results of the ESI studies have provided support for the constructive episodic simulation hypothesis.

Additional Cognitive/Behavioral Tests

While the evidence we have considered so far has focused on the *processes* shared by memory and imagination, the constructive episodic simulation hypothesis also makes claims about shared *content*, namely, that imagined events are constructed, at least in part, by recombining elements of specific past personal experiences. Several cognitive/behavioral studies have reported evidence that is generally consistent with this claim by showing that, for example, phenomenological features of remembered and imagined events are affected similarly by such variables as temporal distance from the present (D'Argembeau and van der Linden, 2004) and contextual familiarity (Szpunar and McDermott, 2008). Further evidence along these lines comes from a study that examined perspective or vantage point for remembered past and imagined future events (i.e. first- vs. third-person perspective; McDermott et al., 2016). Both remembered past and imagined future events were experienced predominantly from a first-person perspective.

Perhaps most strikingly, McDermott et al. (2016) examined the spatial distribution of third-person perspectives adopted (e.g. "seeing" one's self from behind, in front, above, below, etc.), and found that they were nearly indistinguishable during episodic memories and future thoughts, a finding that the authors noted fits well with the constructive episodic simulation hypothesis.

More recently, Thakral, Madore, and Schacter (2019) attempted to provide a strong test of the claim that simulated future events rely on the recombined contents of past episodes by assessing whether content-specific episodic information, such as people or locations from particular past episodes, is retrieved and used when people simulate an imagined future experience. Participants initially recalled past episodes that each contained two critical episodic details: a location and person, and then imagined future episodes using pairs of person and location details that were recombined from different memories. Participants rated the vividness with which they experienced each location and person in both remembered and imagined events. To examine whether the content associated with individual episodic details is shared across remembered and imagined events, Thakral et al. (2019) examined whether vividness ratings for person and location details given during the memory task could be used to predict the vividness ratings assigned to the two kinds of event details during the simulation task. If imagined future events are based upon the recombined contents of particular episodic memories, as maintained by the constructive episodic simulation hypothesis, then vividness of individual imagined details should covary with the vividness of those same details in the episodic memories from which they were drawn. This is exactly what was found. To address the possibility that details used to construct a novel episode are based on general knowledge of, or familiarity with, the person or location rather than specific episodic information, participants also rated their knowledge of/familiarity with each person or location in everyday life, ranging from not very familiar to very familiar (on a scale of 1 to 5). Critically, even when the level of familiarity was accounted for, a significant relationship between vividness of remembered and imagined person details and place details remained.

Of course, not all cognitive/behavioral evidence reveals similarities between remembered past and imagined future experiences; numerous differences have been documented (see Schacter et al., 2012). Importantly, our initial formulation of the constructive episodic simulation hypothesis attributed some of these differences to "the more intensive constructive processes required by imagining future events relative to retrieving past events" (Schacter and Addis, 2007b: 782). We will elaborate on this point in the next section when we turn our attention to neural evidence that bears on the constructive episodic simulation hypothesis.

Assessing the Constructive Episodic Simulation Hypothesis: Neural Evidence

Neuroimaging of the Core Network

Neuroimaging has provided compelling support for the constructive episodic simulation hypothesis by demonstrating extensive overlap between patterns of activity

associated with memory and simulation (Addis, Wong, and Schacter, 2007; Okuda et al., 2003; Szpunar, Watson, and MacDermott, 2007; Thakral, Benoit, and Schacter, 2017b). For example, Addis, Wong, and Schacter (2007) had participants remember past or imagine future events in response to word cues, press a button when the event was in mind, and elaborate for the remainder of the twenty-second trial. This construction-elaboration paradigm enabled separation of activity associated with the initial generation of events from the subsequent fleshing out of the event representation, revealing maximal neural overlap during the elaboration phase. Subsequent studies have also reported overlap of memory-related brain activity with activity during other forms of simulation, including imagining hypothetical scenes (Axelrod, Resse, and Bar, 2017; Hassabis, Kumaran, and Maguire, 2007a), past events that never occurred (Addis et al., 2009) and counterfactual events (De Brigard et al., 2013). Importantly, the common activity associated with memory and simulation cannot be explained as an artifact of a simulation task that allows participants to simply recast a remembered past event as occurring again in the future. Specifically, Addis et al. (2009) experimentally recombined key details (people, places, objects) to be included in imagined events and still observed considerable neural overlap with remembered events. A recent meta-analysis of twelve studies (Benoit and Schacter, 2015) localized overlapping activity primarily within the default mode network, including regions such as medial prefrontal cortex, lateral temporal and parietal cortices, posterior cingulate and retrosplenial cortices, and the medial temporal lobes (including the hippocampus). These results provide strong support for the designation of this set of regions as the *core* network mediating both memory and simulation, reflecting recruitment of a fundamental constructive process both when remembering and imagining (Hassabis, Kumaran, and Maguire, 2007a; Hassabis et al., 2007b; Schacter, Addis, and Buckner, 2007). Note that despite their extensive overlap, the default mode network is broader than the core network; it contains some cortical regions (e.g. parts of the superior frontal gyri) that are not part of the core network (see Benoit and Schacter, 2015).

Neuroimaging has also revealed differences between memory and simulation. Specifically, relative to remembering past events, imagining future events is associated with greater activity in a number of core network regions; of particular interest is differential simulation-related activity in the hippocampus, initially observed by Addis, Wong, and Schacter (2007) during event construction, and evident in a meta-analysis of eleven studies (Benoit and Schacter, 2015). We have investigated potential explanations for increased hippocampal activity during simulation (for detailed discussion and a multicomponent model, see Addis and Schacter, 2012; for a meta-analysis, see Viard et al., 2012; and for recent related evidence, see Thakral, Benoit, and Schacter, 2017a). In part this activity is related to the successful encoding of simulated events (Martin et al., 2011; Thakral, Benoit, and Schacter, 2017a), but the balance of evidence suggests that it largely reflects the *construction* of novel simulations (e.g. Addis and Schacter, 2008; Campbell et al., 2018; Gaesser et al., 2013; van Mulukom et al., 2013; for discussion, see Schacter, Addis, and Szpunar, 2017; Sheldon and Levine, 2016). Findings of higher activity during memory relative to simulation are less commonly reported (e.g. Gilmore, Nelson, and McDermott, 2016), but have

been observed in the hippocampus when the imagined events, having been "pre-simulated" earlier, are retrieved rather than constructed during scanning (see Addis et al., 2011, for discussion).

Despite the consistency of the neuroimaging evidence, the nature of the fundamental constructive process that underpins memory and simulation remains a topic of debate (cf. Palombo et al., 2018; Roberts, Schacter, and Addis, 2018). The scene construction theory (Hassabis, Kumaran, and Maguire, 2007a; Hassabis et al., 2007b; Mullally and Maguire, 2014) posits that the hippocampus is commonly engaged by the construction of a scene that forms the basis of both remembered and imagined events. Indeed, any realistic event representation is highly likely to be played out within a scene (Robin, Wynn, and Moscovitch, 2016) given that space is intrinsic to our experience of reality. However, scene construction theory does not adequately explain differences between memory and imagination, including why the hippocampus is more intensively engaged during imagination. In contrast, the constructive episodic simulation hypothesis emphasizes the centrality of relational processing (Cohen and Eichenbaum, 1993) common to both memory and simulation, while also outlining the ways in which relational processing is more intensive during imagination. Specifically, while the reconstruction of an episodic memory requires the reactivation and reintegration of *existing relations* between details, the construction of a novel imagined event necessitates the *formation of novel relations* by recombining and integrating details retrieved from disparate episodic memories into a coherent event representation (Addis and Schacter, 2012; Schacter and Addis, 2007b). This perspective is not mutually exclusive with scene construction theory; the (re)constructed relations include spatial relations comprising scenes. Importantly, however, we go beyond spatial context to include the other perceptual and conceptual components comprising these often multifaceted and dynamic event representations (e.g. objects, people, actions, time, and emotions). As such, the constructive episodic simulation hypothesis offers a more general theory of memory and simulation that also addresses core network activity beyond the hippocampus (see also Addis, 2018).

Recruitment of extra-hippocampal aspects of the core network reflect recruitment of other processes involved in both memory and imagination, such as attention to and maintenance of event representations (inferior lateral parietal cortex; e.g. Cabeza, Ciaramelli, and Moscovitch, 2012; Thakral, Benoit, and Schacter, 2017b) and mental imagery (precuneus; e.g. Cavanna and Trimble, 2006). Moreover, regions within and beyond the core network mediate particular types of content that typically comprise event representations (Addis, 2018), including contextual information (parahippo-campal gyrus, retrosplenial cortex; Bar and Aminoff, 2003), as well as lower-level perceptual content (e.g. visual network; Binder et al., 2009). There is behavioral evidence to suggest that remembered events tend to be more vivid than imagined events (e.g. D'Argembeau and van der Linden, 2004) and in line with these observations, Addis et al. (2009) found that relative to imagined events, remembered events were associated with greater activity in visual cortices. Therefore, the degree to which these different processes and types of content contribute differentially to memory and imagination will influence the spatial distribution of activity across the core network and related networks (Addis, 2018).

Although the focus of the constructive episodic simulation hypothesis has been on the role of episodic memory in the imagining of hypothetical events, it is also important to consider semantic memory processes. Indeed, Schacter and Addis (2007b) suggest that anterior temporal activity evident during both remembering and imagining likely reflects the personal semantic content (e.g. knowledge of familiar people, common activities) inherent to autobiographical event representations. Subsequent findings from patient and neuroimaging studies have indicated that, relative to remembering, simulating novel events may be more reliant on semantic processes. Specifically, semantic dementia patients who are able to retrieve episodic memories in similar detail as healthy controls, and can recast past events into the future, are nevertheless unable to simulate novel future events (Irish et al., 2012). This differential impairment suggests that a schematic framework may be a critical component of an imagined event; once generated, the framework can be fleshed out with relevant episodic and semantic content. Consistent with this idea, neuroimaging studies have reported differential activity for imagining relative to remembering in regions mediating schematic and semantic knowledge (medial prefrontal and lateral temporal cortices, respectively; e.g. Addis, Wong, and Schacter, 2007; Addis et al., 2009; Okuda et al., 2003; see also, Abraham, Schubotz, and von Carmon, 2008). It is likely that the degree to which a schematic framework is required during imagination exists along a continuum, with recasting a past event into the future at one end and imagining novel – and even implausible – events at the other (Addis, 2018; Szpunar, Spreng, and Schacter, 2014). Indeed, semantic information is particularly important when imagining events that fall outside of one's own experience. In a recent fMRI study (Roberts et al., 2017), we had participants imagine events involving a set of congruent details (e.g. "Mum," "living room," "handbag") or incongruent details (e.g. "Dad," "conference poster," "gym"). When constructing a simulation was more challenging, as in the incongruent condition, the anterolateral prefrontal cortex was differentially recruited, likely reflecting an increased reliance on semantic processes such as conceptual expansion to support the construction of a plausible event framework from disparate details.

Manipulating episodic retrieval

Although the foregoing evidence is broadly consistent with the constructive episodic simulation hypothesis, because of its correlational nature, interpretive caution is required. We have recently taken two new approaches in an attempt to provide stronger evidence bearing on the neural substrates of constructive episodic simulation. First, we have attempted to *manipulate* the involvement of episodic retrieval during fMRI scanning by using the aforementioned ESI procedure. Madore et al. (2016) scanned participants after an ESI or control induction while they imagined a future event that could happen to them within the next few years in response to a verbal object cue. We used the construction-elaboration paradigm (Addis, Wong, and Schacter, 2007), in which participants press a button to indicate when they have constructed an imagined event, and then elaborate the details of that event for the remainder of the twenty-second trial. Participants also performed an object

comparison control task in which they generated two objects that were related to each object cue and put them together in a size sentence (e.g. "X is larger than Y is larger than Z"). Similar to the future imagining task, participants were told to press a button once they had constructed the size sentence, and to then elaborate on a semantic definition of each object for the remainder of the trial.

Results revealed increased activity throughout the core network during the future imagining task compared with the object comparison task following both ESI and the control induction, thus replicating and extending earlier results. Critically, following ESI compared with the control induction, there was significantly increased activity in core network regions previously linked with retrieval of episodic detail, notably left hippocampus and right inferior parietal lobule/angular gyrus. Resting-state connectivity analyses using these hippocampal and inferior parietal lobule areas as seed regions revealed significantly stronger coupling with other core network regions after ESI compared with the control induction. Because the involvement of episodic retrieval was experimentally manipulated via ESI, these findings provide strong evidence for a role of episodic retrieval processes in future imagining, in line with the constructive episodic simulation hypothesis.

Madore et al. (2019) took a similar approach to investigating the contribution of episodic retrieval to divergent creative thinking: after receiving ESI or a control induction, participants were scanned while they completed either the AUT task described earlier, which draws on divergent thinking, or the OAT control task, which makes little demand on divergent thinking. Similar to the previous results, ESI produced increased hippocampal activity during the AUT vs. the OAT. Moreover, a multivariate ICA (independent components analysis) revealed that following ESI there was stronger connectivity during the AUT between the core network and a frontoparietal brain network previously linked to cognitive control, and this increased coupling extended to a subsequent resting-state scan. The increased connectivity between core and frontoparietal control networks following ESI is notable because coupling between these two networks has been linked to creative cognition in previous research (see Beaty et al., 2016).

Another approach that goes beyond purely correlational evidence to assess the constructive episodic simulation hypothesis entails using transcranial magnetic stimulation (TMS) to manipulate the activity of a region thought to be critical for both episodic memory and simulation by temporarily disrupting it. Thakral, Madore, and Schacter (2017) examined the effects of applying inhibitory TMS to the left angular gyrus, a key node of the core network associated with retrieval of episodic detail, on subsequent tasks in which word cues were presented and participants (a) remembered a past experience, (b) imagined a future experience, or (c) generated semantic associates. Compared with a condition in which TMS had been applied to a control region not thought to be important for retrieving episodic details (the vertex), TMS to the left angular gyrus produced a selective reduction in internal/episodic details during remembering and imagining, while having the opposite effect on external details and no effect on generating semantic associates. Again, the results provide empirical support for the constructive episodic simulation hypothesis by showing selective and similar effects of TMS to the left angular gyrus on episodic memory and simulation.

Constructive Episodic Simulation and Memory Errors

A key theme in our initial articulation of the constructive episodic simulation hypothesis (Schacter and Addis, 2007a, 2007b) was that the same flexible retrieval and recombination processes that render episodic memory useful for simulating future events could also make the system prone to error (for related ideas, see Dudai and Carruthers, 2005; Suddendorf and Corballis, 2007). Only recently, however, has directly relevant experimental evidence appeared.

One line of evidence comes from Devitt et al. (2016), who adapted the experimental recombination procedure described earlier. Participants initially generated person-place-object autobiographical memories, and the experimenter then recombined elements of the episodes: either partial recombinations (one element of a memory changed) or full recombinations (two elements changed). In a second session, participants imagined the recombined items as events that might have occurred in the past. Finally, in a third session, participants judged whether recombined detail sets and "real" detail sets (i.e. original person-place-object combinations) belonged to a real event, an imagined event, or was a novel recombination they had not seen previously. In two experiments, Devitt et al. (2016) found that imagining partial or full recombination modestly but significantly boosted the number of "real" judgments assigned to recombined events. These autobiographical memory conjunction errors were more frequent for partial than full recombinations, likely reflecting greater similarity of imagined past events to an actual event for the partial recombinations.

More recently, Carpenter and Schacter (2017) linked flexible recombination with memory errors that result from mistakenly combining elements of distinct but related episodes. They attempted to isolate the influence of flexible recombination processes on memory errors by adapting an *associative inference* paradigm (e.g. Zeithamova and Preston, 2010). In this paradigm, participants are required to combine information from separate episodes involving people, objects, and contextual settings in order to make associative inferences about individuals who are linked to one another because each is paired with the same object in distinct settings (i.e. scenes depicting the individual, object, and a background setting or context). Carpenter and Schacter (2017) found that participants are more susceptible to making memory errors that are attributable to mistakenly combining contextual details from related episodes when they made *correct* inferences about the relations between the people in these episodes (i.e. judged correctly that the individuals were linked by a common object) than when they made *incorrect* inferences. Of key theoretical importance, this increase in memory errors for correct inferences occurred only when contextual details were probed *after* an associative inference test that engaged flexible recombination processes; there was no difference in memory errors for correct vs. incorrect inferences when memory for contextual details was probed *before* the associative inference test (i.e. before flexible recombination processes were engaged). Carpenter and Schacter (2018) extended this phenomenon to the domain of value memory and reward processing in a paradigm in which individuals who were designated high, low, or no value were linked to one another via a common object. Participants

mistakenly attributed high value to a low- or no-value individual more often when they made correct vs. incorrect inferences about the relation between these individuals (i.e. judged correctly that the individuals were linked by a common object). Critically, however, once again this increase in memory errors was observed only when memory for value details was probed after the associative inference test that engaged flexible recombination processes.

Carpenter and Schacter's (2017, 2018) data provide clear evidence linking flexible recombination and memory errors, in line with the constructive episodic simulation hypothesis. However, Carpenter and Schacter's paradigm did not involve any future thinking. The same can be said of Devitt et al.'s (2016) experiments, in which participants imagined events that might have occurred in the past (for related evidence, see Gerlach, Dornblaser, and Schacter, 2014). Yet in our initial articulation of the constructive episodic simulation hypothesis, we emphasized not only that flexible recombination processes could result in memory errors, but also that such errors might arise as a consequence of using flexible recombination to simulate possible *future* experiences. Several recent studies provide relevant evidence. Dewhurst et al. (2016) had participants encode lists of semantically related words by thinking about how the list items might be used in a future situation that requires planning, with reference to a past event, or by rating each item's pleasantness. Encoding with reference to a future situation produced higher levels of subsequent false recall and false recognition of a non-presented, semantically related "critical lure" word (Roediger and McDermott, 1995) than did the other two encoding conditions. Dewhurst et al. (2018) extended this pattern of increased false recognition following future-related encoding to schema-related lure items. Devitt and Schacter (2018) found that when participants simulated positive or negative outcomes of hypothetical future events before learning the actual outcomes of those events, neutral outcome events were later remembered more positively because of a liberal response bias for positive information. Devitt and Schacter (2018) also found the same positivity bias after participants simulated positive outcomes to imagined past events, suggesting that biased remembering in this paradigm reflects the qualities of episodic simulations in either temporal direction.

Overall, this evidence supports a key assertion of the constructive episodic simulation hypothesis that flexible recombination and episodic simulation, including but not limited to future-oriented simulation, can contribute to memory errors (for further discussion of conceptual issues related to episodic simulation and memory errors, see Devitt and Addis, 2016; Mahr and Csibra, 2018; Schacter, 2012; Schacter et al., 2018).

Conceptual Development of the Constructive Episodic Simulation Hypothesis

Our initial articulation of the constructive episodic simulation hypothesis emphasized that imagining future experiences relies on episodic memory as conceived by Tulving (2002). However, this broad-brush invocation of episodic memory

requires refinement. For example, Tulving (2002) emphasized the importance of "autonoetic consciousness" – awareness of self in time – as a defining feature of episodic memory. Yet there is little evidence that such autonoetic consciousness is critically involved in all the forms of imagination that we have linked to episodic memory, including simulation of future experiences, means-end problem-solving, and divergent creative thinking. In our initial papers (Schacter and Addis, 2007a, 2007b), we discussed the role of flexible recombination processes in future imagining, and over the years we have placed increased theoretical emphasis on these kinds of episodic retrieval processes in the construction of various kinds of mental events, with little theoretical emphasis on autonoetic consciousness. In a related vein, Schacter and Madore (2016) have proposed that the ESI procedure discussed earlier primarily impacts an *event construction* process that supports assembling a mental event with details related to people, places, objects, and actions. We think that it is this kind of constructive retrieval process that is central to the various manifestations of imagination discussed here.

Related to this point, although we initially emphasized that imagination and simulation rely on episodic memory, episodic memory itself can be thought of as a form of mental simulation (for detailed articulations of this view, see Addis, 2018; De Brigard, 2014; Michaelian, 2016). Although memories contain original elements of experiences, these details are woven together with imagined content (Michaelian, 2016). Memories are embellished and gaps "filled in" with relevant semantic and schematic knowledge as well as details from other events, so that remembering is not only reconstructive but constructive (Bartlett, 1932). That we can remember events from unexperienced visual perspectives (e.g. seeing ourselves) is compelling evidence of an imaginative process during remembering. Moreover, St. Jacques et al. (2018) recently reported that prefrontal and parietal regions recruited when remembering past events from novel visual perspectives overlapped more with the neural correlates of an imagination task (imagining counterfactual past events) than veridical remembering, further supporting the notion that remembering can be similar to imagination and so can be thought of as a kind of simulation.

Remembered and imagined events rely on the same cognitive processes (reactivation of pre-existing schemas to guide construction, reactivation of relevant semantic and perceptual content, relational processing, as well as attention to, and encoding of, the constructed representations) and the same brain networks (i.e. the core network), albeit to varying degrees. Together, the utilization of the same content and cognitive processes explains both the neural overlap and neural differences between memory and imagination. We have previously argued that while both memory and imagination rely on relational processing, there are nevertheless critical differences in the degree and types of relational processes recruited by the two tasks: the re-integration of previously associated details during remembering places lower demands on relational processing than recombining details to create new associations during imagination (Schacter and Addis, 2007b). However, given that remembering also involves some amount of imaginative construction (Bartlett, 1932), it follows that some degree of recombining also occurs even during remembering. Moreover, when imagining events, some level of reintegration occurs (e.g. chunks of related content are incorporated with novel

information; entire memories are reintegrated and recast into the future with minimal changes). Thus, Addis (2018) suggests that the contribution of relational processes to simulation may be better conceptualized as "associative history" of the composite elements: While veridical memories comprise the most preassociated elements, novel imaginings comprise the least. It is possible that the overall associative strength is manifest as fluency (Michaelian, 2016), explaining why memories are typically brought to mind more quickly and with less difficulty than imagined events (e.g. Anderson, Dewhurst, and Nash, 2012).

Concluding Comments: Big Questions

During the past decade, various kinds of evidence have provided empirical support for key components of the constructive episodic simulation hypothesis, namely that episodic retrieval contributes to simulations of various kinds, that imagined and remembered events draw on similar episodic contents, and that flexible recombination processes used to support episodic simulation can contribute to memory errors. The hypothesis has also evolved, with increased emphasis on attempting to understand core constructive retrieval processes underlying simulations that occur during both imagining and remembering. For each of the key components of the hypothesis, some major questions remain to be investigated: Does episodic retrieval contribute differently to different kinds of simulations, such as simulations that support future imagining, atemporal scene construction, divergent thinking, and counterfactual simulation? How do episodic contents interact with semantic and schematic processes during various forms of simulation? Can we identify neural markers of the flexible recombination processes that contribute to both episodic simulation and memory errors? We think that deeper analyses of all these questions will be essential to achieving a better understanding of the relation between memory and imagination.

Acknowledgments

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