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Time Is Not of the Essence

Understanding the Neural Correlates of Mental Time Travel

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INTRODUCTION

The precise relationship between memory and imagination has been a matter of debate for centuries (e.g., Aristotle [Barnes, 1984]; Hobbes, 1668; Hume, 1739; Russell, 1921). But at no time has this debate seen a more remarkable development than in the last two decades, as numerous behavioral, neuropsychological, and neuroimaging studies have consistently shown that our capacity to remember episodes that occurred in the past and our ability to imagine possible events that may occur in the future are profoundly intertwined. Although somewhat cautiously, many of these results have been interpreted as providing evidence in favor of the view that episodic memory (i.e., our capacity to remember past personal events) and episodic future thinking (i.e., our ability to imagine possible future personal events) (Atance & O'Neill, 2001; Szpunar, 2010) should be seen as two operations of a single cognitive system that enables "mental time travel" (MTT) (Tulving, 1985): the allegedly uniquely human psychological capacity through which we "mentally project ourselves in time" by entertaining mental simulations of events whose contents are either about the past or about the future (Suddendorf & Corballis, 1997). According to this perspective, then, the psychological system for MTT operates upon representations with temporal or "tensed" contents. This view naturally leads to the hypothesis that it is the *temporal* nature of the content of the mental simulations involved in the aforementioned results that accounts for the common engagement of neural mechanisms during episodic memory and future thinking. Time, as it were, is thought to be of the essence.[1]

However, as we review in the present chapter, the story is not so simple. As it turns out, there is a large amount of evidence that is difficult to reconcile with the view that what accounts for the common engagement of the neural substrates of episodic memory and future thinking is the fact that the contents of such mental simulations are tensed. Indeed, we argue that much of this evidence actually suggests, somewhat paradoxically, that when it comes to the neural mechanisms of mental time travel, time is not of the essence—or, at least, not essential as part of the *content* of the simulation. Instead, we suggest that what accounts for this common engagement of brain regions is that the mental simulations they support *unfold* in time, regardless of whether or not they are *about* time. To use a distinction familiar to philosophers (Cussins, 1990; Dennett, 1978; Hurley, 1998): we argue that these results are better explained if time is not considered essential for the *content* of the simulation, but rather for its representational vehicle—or *structure*, as we prefer to call it, for reasons that will soon become clear.

This chapter is divided into five sections. In section 1 we review critical experimental results that have been thought to support the view that episodic memory and future thinking share a common neural substrate. We then explain how these results have been interpreted as providing evidence in favor of a cognitive system for MTT. In section 2 we review evidence suggesting that the temporal nature of the content of the mental simulation is not necessary for the engagement of the neural substrate thought to be involved in MTT. To account for these discrepant results, in section 3 we use a familiar philosophical distinction between representational contents and representational vehicles to explain the difference between the content and the structure of a temporal simulation. We show how these two dimensions—content and structure—are orthogonal to one another, and how focusing on the temporal structure rather than the tensed content of the mental simulation may help to accommodate both the evidence and the counterevidence reviewed in sections 1 and 2. Our discussion in this section will also deal with the issue of atemporal simulations—that is, simulations that are neither of the past nor the future. Next, in section 4, we compare our proposal to some prominent accounts of the brain activation during MTT, namely the episodic simulation hypothesis (Schacter & Addis, 2007) and the scene construction hypothesis (Hassabis & McGuire, 2007). We argue that our account is not only compatible with these hypotheses but also explains why they are not incompatible with each other. To anticipate, we suggest that scene construction is best understood as a hypothesis about the structure of the mental simulation, while the episodic simulation hypothesis is best understood as an account of its content. Finally, in section 5, we discuss three possible objections and some implications that may follow from our view.

1. THE TENSED-CONTENT VIEW

Although it is customary to cite Tulving (1985) when introducing the notion of mental time travel and its relation to episodic memory, the truth is that this idea predates him by centuries. Here is Saint Augustine, for instance, reflecting upon the contents he finds within the "vast court of his memory":

> There be all which I remember, either on my own experience, or other's credit. Out of the same store do I myself with the past continually combine fresh and fresh likenesses of things which I have experienced, or, from what I have experienced, have believed: and thence again infer future actions, events and hopes, and all these again I reflect on, as present. (Augustine, 1991)

Indeed, the idea that memories of past experiences both guide and constrain our imaginations of possible states of affairs found further reaffirmation in the work of

British Empiricists (Hobbes, 1668; Hume, 1739; Locke, 1689). What is unquestionable, though, is that Tulving provided the first piece of empirical evidence in support of the conjecture that our capacity to imagine possible future events—episodic future thinking (Szpunar, 2010)—critically depends on our capacity to remember episodes from our personal past (Tulving, 1985). In an oft-quoted exchange, Tulving (E. T.) asked amnesic patient K. C. (referred to here as N. N.) what he will be doing tomorrow (Tulving, 1985, 4):

E. T. "Let's try the question again about the future. What will you be doing tomorrow?" (There is a 15-second pause.)
N. N. smiles faintly, then says, "I don't know."
E. T. "Do you remember the question?"
N. N. "About what I'll be doing tomorrow?" E. T. "Yes. How would you describe your state of mind when you try to think about it?" (A 5-second pause.)
N. N. "Blank, I guess."

Patient K. C. was 30 years old when he suffered a severe head injury in a motorcycle accident. A number of regions in K. C.'s brain were significantly compromised (Rosenbaum et al., 2005), including the medial temporal lobes (MTL), damage to which had been previously associated with impairments in episodic memory (Scoville & Milner, 1957). Indeed, although K. C. could still remember many facts about the world from before his accident—that is, his semantic memory was preserved—he was unable to remember many personally experienced events from his past (i.e., retrograde amnesia), and he was incapable of forming new episodic memories about events that he experienced after the accident (i.e., anterograde amnesia). This observation—that in addition to having his episodic memory compromised, K. C. was also incapable of conjuring up imaginations about possible personal future events—constituted a substantial piece of evidence for the claim that episodic memory and future thinking may share common neural mechanisms enabling MTT.

Further support for this claim came from another well-known case. In 2002, Klein, Loftus, and Kihlstrom (2002) described the case of D. B., a 78-year old man who suffered severe retrograde and anterograde amnesia as a result of anoxic encephalopathy. Although unfortunately there is no information about the integrity of D. B's brain after the accident, his neuropsychological evaluation clearly revealed that despite a profound deficit in episodic memory, his performance in other cognitive tasks, including semantic memory, scored within normal limits. Confirming Tulving's prior observation, Klein and colleagues demonstrated that D. B. was not only incapable of remembering past autobiographical events but was also unable to imagine possible personal future episodes. However, to test whether or not D. B.'s deficits in episodic future thinking extended to non-personal or "semantic" future events, Klein and colleagues asked him to remember issues in the public domain (e.g., medical, environmental, political) that were important in the past and to think of possible issues in such domains that might be important in the future. Since D. B.'s performance in this task did not differ from that of controls, Klein and colleagues suggested a dissociation between our capacity to remember past and imagine possible future personal events and our ability to remember past and imagine possible future non-personal events—a sort of "semantic" future thinking.

Around the same time, Atance and O'Neill (2001) published an influential paper providing further neuropsychological and developmental evidence to the effect that episodic memory and future thinking are not only profoundly interconnected but also critically dissociated from semantic memory and semantic future thinking. It only took two more years for cognitive neuroscience to produce neuroimaging evidence supporting these observations. A 2003 positron emission tomography study by Okuda et al. showed common engagement of brain regions, specifically MTL structures, during both episodic memory and future thinking, in contrast with a control task requiring semantic retrieval. Moreover, Okuda and colleagues found that many areas in the MTL showed equivalent or even greater levels of activation during thoughts about a possible personal future than during thoughts about an actually experienced past event.

Behavioral studies soon followed suit, as a number of results showing further parallels between episodic memory and future thinking started to emerge. For instance, using a variation of the memory characteristics questionnaire (Johnson et al., 1988), D'Argembeau and Van der Linden (2004) showed similar effects of valence and temporal distance for both episodic memory and future thinking. In a subsequent study, D'Argembeau and Van der Linden (2006) showed that certain dimensions known to affect memory for past events, such as emotion regulation and visual imagery, have parallel effects in episodic future thinking. Likewise, Spreng and Levine (2006) showed that the temporal distribution of both episodic past and future thoughts could be modeled on a logarithmic scale, as it was more common for subjects to generate events closer to the moment of the simulation than more remote events, suggesting common effects of temporal distance for both episodic memory and future thinking.

2007 was, however, the *annus mirabilis* for research in the neural correlates of mental time travel, as three different labs reported three independent studies yielding highly consistent results. In the first study, Szpunar, Watson, and McDermott (2007) asked subjects to either remember a past personal event, imagine a possible personal future, or imagine a fictitious non-personal event featuring Bill Clinton. Their analysis revealed that thinking about a personal past event and a personal future event, but not thinking about a non-temporal and non-personal event, commonly engages the medial prefrontal cortex (mPFC)—mainly BA 10—the posterior cingulate cortex (pCC), the parahippocampal cortex, and the superior occipital lobe toward the cuneus. In a second study, also employing fMRI, Addis, Wong, and Schacter (2007) used concrete words to cue participants, who were asked to either remember a past episode, imagine a possible future event, or create a sentence. Consistent with previous results, they found remarkable overlap between episodic memory and future thinking, as compared to sentence creation, in regions known to be associated with episodic recollection (Cabeza & St. Jacques, 2007; St. Jacques & De Brigard, 2015). Notably, this common engagement occurred in many of the same regions found by Szpunar and collaborators (2007): mPFC—including BA 10—MTL, pCC, and left precuneus. Unlike Szpunar et al. (2007), though, Addis and collaborators did find greater hippocampal activity during episodic memory and future thinking relative to the control condition, suggesting both that the hippocampus could have been involved in the non-personal simulations in Szpunar et al.'s study (see discussion later in this chapter), and that the hippocampus might be indispensable for MTT.

This last observation—that the hippocampus is critical for both episodic memory and future thinking—received even stronger support from the third study, in which Hassabis and colleagues (2007) asked 5 patients with hippocampal amnesia, and 10 healthy controls, to imagine possible new experiences in response to verbal cues (e.g., "Imagine you're lying on a white sandy beach in a beautiful tropical bay"). Participants' descriptions of their simulations were transcribed and coded to assess how rich, detailed, and spatially coherent they were. The results of this study clearly showed that amnesic patients' descriptions of their simulations were less rich, contained fewer details, and were less spatially coherent than the descriptions produced by controls. Indeed, a further study by Race and colleagues (2011) replicated this result, and found that the deficit in the patients' descriptions was independent of their narrative abilities (see also Verfaellie, Race, & Keane, 2012, and Bartsch et al., 2011, for further support).

In the last eight years, the number of studies reporting overlaps in the neural structures underlying episodic memory and future thinking has skyrocketed (Schacter et al., 2012), consolidating the view that thinking about the past and imagining the future engages a common core brain network (Schacter, Addis, & Buckner, 2007). This common core network substantially overlaps with the so-called *default network* (Spreng & Grady, 2010; Spreng, Mar, & Kim, 2009). These results are so robust that even studies purporting to report counterevidence, upon closer inspection, actually turn out to lend credence to the claim that episodic memory and future thinking share a common neural substrate. Consider a study conducted by Squire and collaborators (2010), in which six individuals with hippocampal damage and eight age-matched controls were asked to remember past events and imagine possible future events while being audio recorded. In line with previous studies, Squire et al. transcribed their participants' descriptions and tallied the number of internal (episodic) and external (semantic) details (Levine et al., 2002), as well as the degree of spatial coherence following Hassabis et al.'s (2007) method. Surprisingly, Squire and colleagues found no differences in the descriptions of patients and controls, and showed that patients had no trouble either remembering past or imaging future events. But this result, far from casting doubt on the relationship between episodic memory and future thinking, suggests exactly the opposite: unlike the Hassabis et al. patients, those in the Squire et al. study did not have retrograde amnesia, so their capacity to remember the past and imagine the future was preserved (Maguire et al., 2010). This finding simply indicates that not all hippocampal damage leads to impairments in mental time travel.[2]

What should we make of these reported cases of hippocampal damage where episodic memory and future thinking are preserved? One possibility is that a difference in the etiology of the hippocampal damage and/or in the progression of the disease may modulate the functional role played by the hippocampus during MTT. Maguire, Vargha-Khadem, and Hassabis (2010), for instance, reported that Jon, a well-described patient with developmental amnesia (Vargha-Khadem et al., 1997), was nonetheless able to imagine possible new experiences, suggesting that an early accident in an ontogenetically underdeveloped hippocampus, as opposed to the abrupt damage in a fully developed adult hippocampus, may influence the degree to which this brain structure is required for mental time travel. Another possibility, not incompatible with the first, is that the patients who were able to generate imaginations about possible future events still had some remaining hippocampal tissue that was recruited during their mental simulations. Although the extent to which Squire et al.'s patients have preserved hippocampal tissue is unclear, we do know that both Jon, the developmental amnesia patient just mentioned, as well as one of Hassabis et al.'s patients, P01, had about 50% of hippocampal tissue intact. Might it be possible that this reduced amount of hippocampal tissue was engaged during their successful episodic future simulations? To answer this question, Mullally, Hassabis, and Maguire (2012) asked patient P01 to engage in future simulation while undergoing fMRI and found that, in fact, his capacity to imagine fictitious experiences was associated with activation in the remaining hippocampal tissue.

Taken together, the experimental results surveyed here strongly suggest that episodic memory and future thinking commonly engage a consistent set of brain regions that includes the mPFC, pCC, MTL (especially the hippocampus), and lateral parietal and retrosplenial cortices, likely corresponding to the functionally well-characterized default network (Andrews-Hanna, Smallwood, & Spreng, 2014; Buckner, Andrews-Hanna, & Schacter, 2008). What accounts for the common engagement of these brain regions during episodic memory and future thinking? A natural hypothesis is readily available: since both episodic memories and future thoughts have temporal or *tensed* contents—that is, they operate upon mental representations that are either about the past or about the future—they tap into the same neural mechanisms and are actually distinct processes of a single brain system responsible for our capacity to entertain tensed mental contents: a single brain system for MTT (Suddendorf, Addis, & Corballis, 2009; Suddendorf & Corballis, 1997, 2007; Tulving, 2002). According to this *tensed-content view*, then, what accounts for the engagement of the same brain regions during episodic recollection and future thinking is a common feature of the (intentional) content of the mental simulations entertained during each task: namely, that both are about time.

2. IS TIME OF THE ESSENCE?

According to the tensed-content view, entertaining a tensed mental simulation—that is, thinking about a past or a future event—is necessary to engage the brain structures associated with a system for mental time travel. However, in the last few years a number of experimental results have cast doubt on this claim. Indeed, some of the very same results that are sometimes heralded in support of the content-based view do not provide univocal evidence in its favor. Consider the study by Hassabis and colleagues (2007) on individuals with hippocampal amnesia. Their participants were asked to imagine *new* experiences, but they were not instructed to mentally place such experiences in a possible future. Presumably, to imagine a new experience is to entertain a mental simulation of a possible event that, even though it has not happened yet, could nonetheless occur in the future. But it need not be this way. To imagine a new experience may just mean to think of a possible hypothetical situation that may or may not occur in one's life, regardless of its precise temporal location. For all we know, the mental simulations entertained by the participants in the Hassabis et al. study may not have featured a temporal stamp in their contents—that is, they may not have been tensed at all (Hassabis & Maguire, 2009, explicitly acknowledge this possibility).

Other studies have yielded results that can be seen as providing evidence against the tensed-content view. For instance, Addis and colleagues (2009) found very similar patterns of brain activation within the default network when participants were instructed to simulate an event with familiar people, objects, and places, either in a possible future or in a possible past. This result speaks against the tensed-content view—and, indeed, against a strict interpretation of the traditional formulation of MTT—in an intriguing way. Consider Tulving's initial influential formulation:

> A normal healthy person who possesses autonoetic consciousness is capable of becoming aware of her own past as well as her own future: she is capable of mental time travel, roaming at will over what *has happened* as readily as over what *may happen*, independently of physical laws that govern the universe. (Tulving, 1985, 5; emphasis added)

If there were a brain system dedicated to mental time travel, as defined by Tulving, then it should be sensitive to mental simulations whose contents are about what *has happened* in one's past and what *may happen* in one's future, but not necessarily to contents depicting events that did *not* happen in one's past. After all, when we remember, we engage in a cognitive activity that aims to bring to mind contents representing previously experienced events, whereas this is not the case when we engage in simulations about events we know did not occur. Of course, although unlikely, it may be possible that the participants in Addis et al.'s (2009) study were simply unsure as to whether or not the imagined past events actually occurred in their past, so they may have tensed the imagined contents as if they had occurred, while granting them less certainty than they did to remembered events. However, further studies speak against this interpretation. For instance, De Brigard and colleagues (2014) asked participants to engage in episodic counterfactual thinking—that is, thoughts about alternative ways in which past personal events could have occurred but did not, or about events that did not occur at all, but might have (De Brigard & Giovanello, 2012)—while undergoing fMRI. Consistent with Addis et al.'s (2009) result, they found engagement of the default network not only when participants were remembering their past but also when they were engaged in episodic counterfactual thought: that is, when they were thinking about alternative ways in which past personal events, which they knew had occurred, could have been different (see also Van Hoeck et al., 2013).

Indeed, neuroimaging evidence suggesting that mentally simulated contents need not be temporally tensed to engage the default network is rapidly accumulating. For instance, Hassabis et al. (2007) reported default network activation during non-temporal simulations (see also Summerfield et al., 2010). Similarly, D'Argembeau and colleagues (2008) instructed participants to imagine general and explicitly tenseless simulations where they engaged in routine activities such as brushing their teeth. They found that these non-tensed simulations produced activation in the medial temporal lobe, and other default network regions, at the same level as activation for explicitly future simulations (see also D'Argembeau et al., 2010). Relatedly, transient episodes of mind-wandering, whereby our attention shifts from ongoing stimuli toward self-generated thoughts, also seems to recruit the default network, even when it is unclear whether or not the simulated self-generated thought is located at a particular time (Christoff et al., 2009). Default network activity has also been reported in non-temporal tasks involving spatial navigation (Spreng, Mar, & Kim, 2009), mentalizing (Hyatt, Calhoun, et al., 2015; Spreng & Andrews-Hanna, 2015), narrative comprehension (Mar, 2011), and counterfactual thoughts about other people (De Brigard et al., 2015). Although it is still possible that all these disparate tasks involve placing the simulated mental content at a particular time, there is no prima facie reason to believe that a temporal component is common to all of them (we return to the issue of atemporal simulations in section 3).

The picture against the tensed-content view is further strengthened by a number of behavioral studies suggesting similarities in performance between tasks involving mental time travel and other kinds of mental simulations. For instance, using a variation on the memory characteristics questionnaire (Johnson et al., 1988) and the autobiographical interview (Levine et al., 2002), De Brigard and Giovanello (2012) reported similar effects of outcome valence in the mental simulation of episodic future and counterfactual thinking as compared to episodic memories. Similar measures were used by de Vito et al. (2012) to investigate the effects of self-relevance and familiarity of setting in imagining episodic future versus atemporal events. De Vito et al. found that, when the familiarity of the context of the simulation as well as the level of self-relevance are kept fixed, imagining the event at a possible future time versus at no particular time at all makes no difference to the phenomenology of the mental simulation. Taken together, these results indicate that the temporal stamp in the content of the mental simulation does not seem to play a prominent role in their phenomenology, suggesting that a tensed content may not be essential for the engagement of the cognitive processes common to episodic memory and future thinking.

But perhaps the most powerful evidence against the tensed-content view comes from recent studies in individuals with hippocampal amnesia. These results show not only parallel difficulties in the simulation of non-temporal events—suggesting that a tensed content is not necessary for the engagement of the hippocampus—but also perfectly preserved capabilities to entertain certain kinds of temporal thoughts. This suggests that a tensed-content may not even be sufficient for hippocampal engagement. On the one hand, initial evidence in favor of the hippocampus being required for non-tensed simulations comes from an interesting study by Rosenbaum and collaborators (2009). Aware of K. C.'s difficulties in remembering the past and thinking about the future, Rosenbaum and colleagues asked K. C. to generate fictional events and to reconstruct well-known fairy tales and Bible stories. Surprisingly, his performance at both tasks was significantly worse than age-matched controls. Further evidence comes from a recent study by Romero and Moscovitch (2012) in which older adults and young adults with MTL damage were cued with sets of words and asked to generate fictional events that included the items referred to by the cuing words. Critically, the events were not supposed to be set at any particular time. Their results showed that both older adults and young individuals with MTL damage generated mental simulations that exhibited less coherence and were more unstructured than their matched controls.

On the other hand, evidence against the hippocampus being required to entertain tensed thoughts comes from a number of recent neuropsychological studies investigating decision-making processes in individuals with amnesia. In one such study, Kwan and collaborators (2013) asked K. C. to engage in a task that required the valuation of future rewards. Surprisingly, despite the fact that K. C. is profoundly impaired when it comes to constructing vivid and coherent simulations of future events, he systematically discounted the value of future rewards on par with controls. These results strongly suggest that thinking about the value of future rewards and thinking about a possible future event are two kinds of tensed thoughts, only one of which depends on the hippocampus. Further evidence for this claim comes from other studies conducted on K. C. For instance, Craver and colleagues (2014) asked K. C. a number of explicit questions about the future, many of which paralleled those used by Klein and colleagues (Klein, 2002), and they found that K. C. was able to produce perfectly normal responses. Consider this excerpt, from a conversation reported in Craver et al. (2014; S. R. = Shayna Rosenbaum, the interviewer):

S. R.: What is the future?
K. C.: Events that haven't happened yet.
S. R.: What is the past?
K. C.: Events that have already happened.
S. R.: Can you change the past?
K. C.: No.
S. R.: Can you change the future?
K. C.: Yes.
S. R.: How?
K. C.: By doing different things.
S. R.: Does what happened in the past influence what happens in the future?
K. C.: Yes.
S. R.: Does what you do now influence what happens in the future?
K. C.: I guess so.
S. R.: Does what you do now change what has happened in the past?
K. C.: No.

And the conversation goes on, with questions about what it means to do something that may affect the future, and what it would mean to be able to travel in time. To all these questions K. C. gave perfectly normal answers, demonstrating not only that he had an appropriate understanding of the concept of time in the absence of episodic memory (contra Hoerl, 1999), but also that he could entertain tensed thoughts—that is, thoughts about times other than the present—without a functioning hippocampus. Indeed, not only was K. C. able to talk about time and discount possible future rewards on par with controls, but he also exhibited regret anticipation and other normal temporal attitudes, as measured by Zimbardo's Temporal Perspective Inventory (Kwan et al., 2013).

Similar studies with other individuals with amnesia have also revealed that they are still able to entertain tensed thoughts. Stuss and Guzman (1988), for instance, reported the case of J. V., a 50-year-old man with profound retrograde amnesia but only mild anterograde amnesia. Despite having forgotten both personal and nonpersonal information about his past, he was able to relearn these facts, and was able to think about them again—although, as reported by Stuss and Guzman (1988), "for these past facts that have been relearned, J.V. has no feeling of personal warmth, intimacy, or belonging that the memory is his, or that he was somehow involved" (27).

Klein and Nichols (2012) made similar observations regarding patient R. B., who was able to remember specific situations from his personal past even though he lacked the feeling of warmth and ownership that usually accompanies our episodic memories. Taken together, these case studies—K. C., J. V., and R. B—although different in detail and etiology, strongly suggest that individuals with impairments in episodic memory and future thinking can nonetheless entertain all sorts of tensed thoughts. Consequently, we surmise that these, along with the behavioral and neuroimaging results reviewed earlier, constitute evidence against the tensed-content view, according to which what accounts for the engagement of the same brain regions during episodic recollection and future thinking is the fact that time features in the intentional content of the mental simulations entertained during each task. Given this counterevidence, time just does not seem to be of the essence.

The challenge, then, is to offer an account that can reconcile all the evidence reviewed in section 1—which suggests an intimate relation between the neural substrates underlying our capacities to remember past personal episodes and to simulate possible future personal events—with all the evidence reviewed in section 2, which speaks against using the temporal content of such thoughts as the unifying factor accounting for the engagement of this common neural substrate. To be fair, many authors have recently considered other views to try to account for this apparent discrepancy, with varying degrees of success. Buckner and Carroll (2007), for instance, suggested that this common brain network supports thoughts that essentially involve self-projection; Hassabis and Maguire (2009) suggested instead that it supports thoughts that involve the construction of a spatial scene; and more recently, Andrews-Hanna, Smallwood, and Spreng (2014) suggested that what these thoughts may have in common is that they are social, goal-directed, and self-generated. Despite the merits of these views (which we discuss later in the chapter), we want to suggest a different approach that may provide a novel way to understand the neural correlates of MTT. Specifically, we suggest that what may account for the common engagement of these brain mechanisms during MTT simulations is not something about the content of these thoughts, but rather something about their structure. But to do that, we must first clarify the distinction between the content and the structure of a simulation.

3. THE CONTENT-STRUCTURE DISTINCTION

A traditional and fundamental distinction in the philosophy of mind is that between *intentional objects* and *intentional contents*. Mental states are intentional: they are *about* something (Brentano, 1874). Intentional objects are those things that mental states are about. They are so-called to distinguish them from mere actual objects, since the objects of our mental states need not exist. Both the paper with which this page is made as well as Santa Claus can be intentional objects, insofar as one can entertain mental states about them; yet only one of them exists. But that which our mental states are about is different from the *content* of our mental states. After all, one can entertain two different thoughts about the exact same object. Lois Lane, for instance, could entertain two entirely different thoughts—even contradictory thoughts—about Superman and Clark Kent, even though both Superman and Clark Kent are the same object. She can do that because the individual referred to by these names can be present to Lois Lane's mind in different modes. The mode in which an intentional object is mentally presented to us is the *intentional content* of a mental state (Crane, 2009; Husserl, 1913).

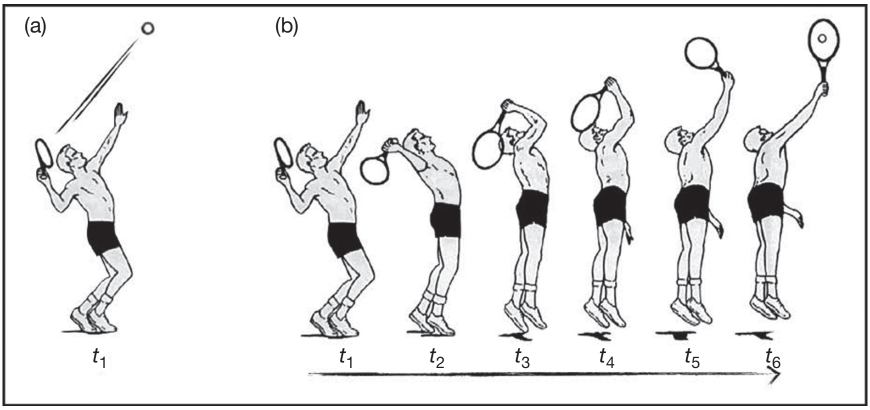
A fundamental project in the philosophy of mind for the last century has been to understand how mental contents relate to their objects. One popular view—often known as *representationalism*—is to think of intentional contents as the information carried by a representation, which in turn is related to its intentional object in some particular way. The precise relationship between the content of the representation and its object is a matter of ongoing debate, as there are a number of prominent theories in the offing and no consensus in sight (e.g., Pitt, 2013). For our current purposes, though, what matters is that most cognitive psychology and neuroscience assumes some form of representationalism. Indeed, many cognitive psychologists and neuroscientists see their research projects as that of uncovering the nature of the representations involved in a particular cognitive task. The same, of course, goes for cognitive neuroscientists studying MTT.

In the philosophy of mind, however, representationalists often draw an important distinction that is seldom acknowledged in contemporary cognitive neuroscience, namely that between *intentional content* and *representational vehicle*. An intentional content, as we mentioned, represents an intentional object, but a certain intentional content is different from the actual particular in the world that does the representing—that is, the thing in the world that carries the information about the relevant intentional object. Think of Andy Warhol's famous mass-produced portraits of Marilyn Monroe. They all were about Marilyn Monroe—she was their intentional object—and they all portrayed her more or less in the same way, that is, carrying more or less the same intentional content (we say "more or less" for reasons that will become clearer later). But Warhol used a number of different materials to create these portraits: silkscreen, textiles, metallic papers, plastic, and so on. Indeed, many artists after him have used all sorts of things to recreate this exact same portrait, with materials as varied as Lego bricks and gummy bears. All these diverse materials constitute different representational vehicles with the same content.

The content/vehicle distinction highlights the fact that there is a difference between the properties of the content of a representation and the properties of the vehicle that carries that content (Dennett & Kinsbourne, 1992; Hurley, 1988). Warhol's portrait of Marilyn made of plastic and the one made of gummy bears may well both depict Marilyn Monroe as being glamorous, but only one of these representations is gooey. This is because being glamorous is a property of the content of the representation, while being gooey is a property of (one of) the representational vehicles carrying such content. The same goes for mental representations. Properties of the intentional contents of a mental representation should not be confused with properties of the representational vehicles carrying the intentional contents. Given that most contemporary representationalists assume that mental states are multiply realizable, most also accept that intentional contents can be carried by different representational vehicles. In fact, the content/vehicle distinction also holds for views that take brain mechanisms to be the representational vehicles of our mental representations. For instance, representationalists who follow the Fodorian tradition of the language of thought consider that the representational vehicles carrying the intentional content of our mental states must have certain physical characteristics (e.g., symbolic locality, sentential structure, etc.), whereas representationalists who follow the connectionist tradition consider that those very same intentional contents must be carried by representational vehicles with a different physical configuration (e.g., distributed, non-local, non-symbolic, etc.). Still, both agree that the representational vehicles must be some kind of brain mechanism.

Unfortunately, most philosophical discussions on representational vehicles have been confined to examples in which the vehicles only vary along *physical* dimensions, such as size, weight, locality, or viscosity (Clark, 2008; Elpidorou, 2013; Rowlands, 2010). Even philosophers who agree that representational vehicles are neural mechanisms tend to confine their disagreements about their possible differences to physical dimensions alone—for example, local versus distributed representations, symbolic versus non-symbolic, and so on. But restricting the range of variations in representational vehicles to physical dimensions overlooks the fact that mental contents tend to vary across a *temporal* dimension as well. This oversight is most likely due to the fact that the philosophical tradition tends to consider mental contents as discrete entities that one can pinpoint to a precise moment during which they perdure, unchanged. As a result, the analogy of a mental representation to a sentence or a picture is enticing, as the vehicles of these kinds of representations need not change with time. But to think that all our intentional contents are discrete and temporally stable mental sentences or pictures utterly simplifies the often continuous and changing nature of the intentional contents we are aware of.[3] For although it is true that we frequently bring to mind thoughts whose contents are relatively stable and short-lived—like pictures and sentences—we also habitually entertain complex mental representations whose contents are experienced as dynamic and unfolding in time. In these cases, information is carried not only by the physical configuration of the representational vehicle but also by its temporal structure.

As an analogy, consider the pictures in Figure 8.1. Panel A depicts a stable representation of a tennis player hitting an overhead ball. As in comic books, the information about the trajectory and force of both the racquet and the ball is



AQ: Please provide figure 8.1 caption.

Figure 8.1

conveyed by motion lines. Despite the fact that the drawing conveys movement, the image is static. Now compare this image with a string of drawings displayed, one after another, as in panel B. Here, a single image by itself fails to convey information about movement and trajectory, as this information is encoded in the dynamical structure of the sequence of pictures, rather than by a single drawing alone.[4] Thus, although both representations are supposed to carry the same content,[5] they do so via two different vehicles. On the one hand, there is a representational vehicle whose structure is *static* and carries information about movement and trajectories with motion lines; on the other hand, there is a representational vehicle with a *dynamic* structure that carries information about movement and trajectories in the succession of the sequence of drawings (see Weiskopf, 2010, for a similar example).

Let us bring the analogy back to the realm of mental representation. Our suggestion is that some intentional contents are carried by representational vehicles whose structures can vary along a temporal dimension—from more static to more dynamic—even if they do not vary in their physical dimensions (i.e., even if both are constituted by distributed neuronal networks, say). Consequently, a mental representation with tensed content (i.e., a thought about the past or a possible future) can nonetheless fail to have a temporal or dynamic structure and have instead a rather non-temporal or static structure. In this sense, whether or not a mental representation has a temporal content (i.e., is tensed) is independent of whether or not it has a temporal structure (i.e., is dynamic). In other words, a temporal component in the content of a mental representation is orthogonal to the temporal dimension of its representational structure.

These considerations suggest a model in which time varies along two axes, content and structure, which in turn segregates temporal mental representations into four quadrants (Figure 8.2). First, there are simulations that involve mental representations with non-tensed contents carried by static representational vehicles. We suggest that paradigmatic semantic memories—such as the thought that triangles have three angles or that 2 is a prime number—belong to this quadrant. Second, there are thoughts that involve entertaining tensed contents carried by static representational

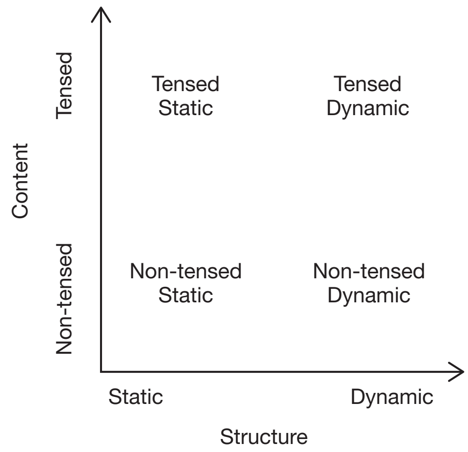


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Figure 8.2

vehicles. Mental representations involving semantic yet temporal information—such as the memory that one graduated from high school or the thought that one has a business trip next month—are presumably within this category. Third, there are mental simulations involving dynamic representational vehicles carrying non-tensed contents. Non-temporal imaginations and certain counterfactual and hypothetical simulations whose representational contents unfold over time would presumably fit this description. Finally, there are thoughts that involve mental simulations of tensed contents with a dynamic representational structure. Paradigmatic examples of episodic memories and episodic future thoughts, in which a mental simulation with a dynamic structure unfolds over time, arguably belong in this quadrant.

We will explore these distinctions further in the next section, where we bring them to bear on our discussion about the neural correlates of MTT. In brief, our suggestion is that the disagreements between the empirical results reviewed in sections 1 and 2 can be resolved if we relinquish the idea that time is essential to the content of the mental simulation and focus instead on its critical role for the structure of the simulation.

4. THE DYNAMIC-STRUCTURE VIEW

In section 1, we surveyed results from a number of studies suggesting a common core brain network underlying episodic memory and future thinking. To account for this common neural recruitment, a number of authors have endorsed, with varying degrees of commitment, what we called *the tensed-content view*. According to the tensed-content view, what explains the engagement of this core brain network during episodic memory and future thinking is the fact that the intentional content of the mental simulations entertained during each task is tensed. Since they operate upon representations with a temporal content, these brain structures likely support a system for mental time travel. However, in section 2, we reviewed a number of empirical results that speak against the tensed-content view, as they suggest that entertaining tensed contents is neither necessary nor sufficient for the engagement of the core brain network—or, at the very least, for the engagement of certain pivotal areas such as the hippocampus.

But the inconsistencies between these two lines of evidence dissipate, we suggest, if one adopts instead a *dynamic-structure view,* according to which what accounts for the common engagement of the core brain network is the fact that the structure of the representation is dynamical, that it unfolds over time, regardless of whether or not it is about time. Consider, for instance, both K. C.'s (Tulving, 1985) and D. B's (Klein et al, 2002) performance in their interviews. The report on K. C. suggests that he was unable to generate coherent thoughts when asked to engage in complex and dynamic simulations of both past and future events. The same occurred with D. B. However, when D. B. was asked to generate thoughts that did not involve the generation and maintenance of a dynamic representation, but rather of information carried by a somewhat more static representation (likened to semantic knowledge), D. B. showed no impairment. The same considerations apply to the more recent report by Craver and collaborators (2014), which clearly demonstrates that K. C. had the capacity to entertain tensed thoughts—that is, thoughts about time—as long as it did not require the generation and maintenance of dynamic simulations. His telegraphic answers seem to reflect the fleeting and non-dynamic nature of the mental representations they express.

These telegraphic answers are also characteristic of the amnesic patients from the Hassabis et al. (2007) study. For example, when asked to imagine "lying on a white sandy beach in a beautiful tropical bay," patient P03 reported that "all I can see is the colour of the blue sky and the white sand," and when probed further simply responded that he could not see anything else, that it felt "like I'm kind of floating." The lack of dynamicity of the mental representation that comes to mind is even clearer in their report from patient P05, who was asked to imagine "standing in the main hall of a museum containing many exhibits."

> Well, there's big doors. The openings would be high, so the doors would be very big with brass handles, the ceiling would be made of glass, so there's plenty of light coming through. Huge room, exit on either side of the room, there's a pathway and map through the centre and on either side there'd be the exhibits. [pause] I don't know what they are [pause]. . . . (1727)

At this point P05 reports that not much more comes to mind. Contrary to Hassabis et al.'s interpretation, this excerpt clearly suggests that P05 was able to imagine a clear spatial scene. It seems unlikely that someone who cannot entertain a mental representation of a spatial scene could generate such a detailed description of a museum room. What this description lacks, though, is dynamicity. It is as though P05 were describing a static picture of a space, rather than a dynamic scene whose components unfold over time. Indeed, there is evidence that individuals with MTL damage are capable of describing such scenes, as long as they are stable pictures (Gaesser et al., 2010; Race et al., 2011; Race et al., 2013). A similar interpretation is available for the results reported in the studies by Rosenbaum and collaborators (2009), as well as Romero and Moscovitch (2012), both of which asked individuals with MTL damage to imagine non-temporal fictional events. These patients' episodically impoverished answers as well as their telegraphic narratives strongly suggest that their simulations lacked dynamicity.

An interpretation consistent with the dynamic-structure view is also available for the neuroimaging results reviewed in sections 1 and 2. For instance, while Szpunar et al. (2007) found no difference in hippocampal engagement between episodic memory, future thinking, and mental simulations involving an imagined Bill Clinton, Addis et al. (2007) did find greater recruitment of the hippocampus for episodic memory and future thinking relative to a control condition is which participants had to construct a sentence. The dynamic-structure view can readily explain this difference, we think, for while it is likely that a mental simulation of a fictitious event involving Bill Clinton can easily have a dynamic structure, the construction of a sentence is paradigmatically a mental process that involves mostly static representational vehicles. The recruitment of the core brain network—and the MTL in particular—during non-MTT simulations as varied as fictitious events (Hassabis et al, 2007), non-temporal episodes (D'Argembeau et al., 2008), imagined past events (Addis et al., 2009), and counterfactual thoughts (De Brigard et al., 2013; van Hoeck et al., 2013) can be accounted for by the fact that all of these simulations involve the generation of dynamic representations. In contrast, tensed thoughts that do not require the deployment of dynamical representations—such as tasks involving future temporal discounting or regret anticipation (Benoit et al., 2011; Craver et al., 2014; Kwan et al., 2013)—neither seem to require the MTL nor engage the core brain network, at least to the same extent.

Another important virtue of the *dynamic-structure view* is that it is not only consistent with the scene construction (Hassabis & McGuire, 2007) and the episodic simulation (Schacter & Addis, 2007) hypotheses, allegedly the two most prominent accounts of the common brain activation during MTT simulations, but it also explains why these two accounts are perfectly compatible with each other. Scene construction, as defined by Hassabis and Maguire, consists in "the process of mentally generating and maintaining a complex and coherent scene or event" (299). The dynamic-structure view is entirely compatible with this perspective as long as the generated and maintained scene or event is thought to be dynamic. As we remarked, individuals with MTL damage—such as P05—can generate and maintain mental scenes as long as they are static. More precisely, their representations can be spatial insofar as their contents can feature spatial relations among components, as was clearly the case with the excerpt from P05's narration quoted earlier. But if the simulation requires the deployment of a dynamic representation of a scene, then it is likely that it would require the involvement of the core brain network, especially the MTL. As such, we suggest that it is best to understand the scene construction view as a hypothesis about the structure rather than the content of the simulation—an interpretation that, we believe, is congenial to the spirit of Hassabis and Maguire's approach.

A similar interpretation is available for a more recent study by Mullally and Maguire (2014) exploring counterfactual thinking in individuals with MTL damage. In this study, Mullally and Maguire asked 6 patients with bilateral hippocampal damage, and 10 controls, to engage in a counterfactual generation and a counterfactual inference task, both of which involved short vignettes. They found no difference in performance in either task between the two groups. However, they also recruited two independent cohorts of healthy participants and asked them to evaluate the degree to which the antecedents in counterfactual conditionals included in both tasks required the generation of mental representations of spatially coherent scenarios. Based on the ratings of these two independent cohorts, Mullally and Maguire split the counterfactual antecedents in two groups: strongly spatial and weakly spatial. Data from both MTL patients and controls were then reanalyzed, and it was found that, as compared to controls, the patients' performance was inferior in the counterfactual reasoning tasks that required the generation of strong—but not weak—spatial mental representations. Unfortunately, it is not clear that Mullally and Maguire's method to assess the degree of spatial strength in the required simulation provides a reliable measure across participants. In our opinion, given the low *N*s of the independent cohorts that rated the antecedents—19 in one case, 9 in the other—it is unlikely that their averaged scores represent a reliable scale to employ as an independent measure to split trials. Nonetheless, even if an appropriate sampling procedure were indeed to reveal a reliable difference in the degree of spatial coherence across counterfactual antecedents, it is still possible that those that are perceived as more strongly spatial are precisely the counterfactual antecedents that involve more dynamic structures. Perhaps a future experiment in which the dynamic structure involved in the mental simulation is kept constant across strong and weak spatial antecedents could help to disentangle this issue. Until then, the results from this study speak in favor of the scene-construction hypothesis as much as the dynamic-structure view.

It is worth noting that the scene-construction hypothesis has also been supported by a wealth of evidence indicating that there are pyramidal neurons with spatial receptive fields in the cornu ammonis (CA) of the hippocampus (O'Keefe & Nadel, 1978), as well as cell assemblies in the entorhinal cortex that map the surrounding space as a grid (Moser et al., 2008). These, along with a large number of related discoveries (Moser et al., 2008), have bolstered the view that the hippocampus and surrounding areas in the MTL (i.e., entorhinal, perirhinal, and parahippocampal cortices) are critical for spatial navigation and representation (Buckner, 2010). Given the engagement of these central regions of the core brain network during MTT simulations, it is natural to account for these common activations by the fact that the mental representations involved are spatial. However, there is also a large amount of evidence clearly indicating that place and grid cells are not only sensitive to space but also to sequential information about spatial navigation. Landmark studies by O'Keefe and Recce (1993) as well as Skaggs and collaborators (1996) showed that the moment of the firing of a place cell in relation to a navigational sequence has a precise timing relation with oscillations in the theta band. More recently, Foster and Wilson (2007) showed that place cells in CA1 in the hippocampus are "timed-locked" to theta oscillations, effectively demonstrating that, prior to performing a learned sequence, such place cells can "pre-play" the forthcoming action by way of firing in succession. These results, we think, indicate that the hippocampus and related areas may not only be coding for space but also for the dynamic relation among the components of a spatial representation. The fact that the representation is spatial may be as essential to the activation of the hippocampus as the fact that the relation among its components is dynamic. And this is precisely what the dynamic-structure view suggests.

The MTL has also been shown to be critical for the encoding and retrieval of all kinds of relations among perceptually distinct experiential components (Cohen & Eichenbaum, 1993; Eichenbaum & Cohen, 2001; Konkel & Cohen, 2009). This line of evidence has buttressed the long-standing view that the hippocampus may act as a "relational binder" whose computational role is not so much to store copies of past experiences but rather to store information about how the components of such experiences were related at encoding and how they should be reactivated together at retrieval (McClelland, 1995). This perspective, along with ample evidence pointing to the reconstructive character of memory (De Brigard, 2011, 2014; Michaelian, 2011; Schacter, Norman, & Koutstaal, 1998), has been marshaled in support of the constructive episodic simulation hypothesis (Schacter & Addis, 2007). According to this hypothesis, what accounts for the common engagement of the core brain network during MTT simulations is the fact that the same reconstructive processes that allow the reconstruction of episodic memories enable the recombination of episodic components during thoughts about possible future events. As a result, given that both episodic memories and future thoughts are cognitive processes that involve the construction of a mental representation from previously experienced episodic details, the fact that they both engage a similar underlying mechanism should come as no surprise.

Thus understood, however, the constructive episodic simulation hypothesis speaks to the constitution of the intentional contents of the representations carried by the identified brain mechanisms, rather than to the structure of the representations. In other words: what the episodic simulation hypothesis suggests is that there is a commonality in the representational processes during episodic memory and future thinking because both representational contents are similarly constituted. Whether or not the structures of such representations are dynamic is something to which the constructive episodic simulation hypothesis remains open. Insofar as the constructive episodic simulation hypothesis is about the content of the representations involved in MTT simulations, it is not incompatible with the scene-construction proposal, which—as we argued earlier—is a view about the structure of their representations.

The difference between an intentional content and a representational structure not only helps to dissipate the apparent inconsistencies in the results reviewed in sections 1 and 2, but it also helps to clarify what the scene construction and the constructive episodic simulation hypotheses are about, as well as to understand why they are perfectly compatible with each other. Moving forward, the challenge is to investigate whether there are other kinds of imaginative contents constituted by episodic details, to what degree they engage the same neural mechanisms as those involved in certain MTT simulations, and to what extent they require the deployment of representations with a dynamic structure.

5. FINAL THOUGHTS

In this chapter we put forth two main theses. First, we argued that what accounts for the commonalities in brain activation between certain kinds of simulations is not so much that their contents are tensed but the fact that their representations are dynamic. As such, we advocated for a dynamic-structure view of the neural correlates of mental time travel rather than a tensed-content view. Second, we suggested that while the scene-construction view should be seen as a hypothesis about the representational structure of the simulations involved in mental time travel, the constructive episodic simulation hypothesis is better understood as a proposal about the constitution of the intentional contents carried by such representations. As such, not only are they not incompatible, they are probably complementary.

There are, however, at least three possible objections that may put pressure against our theses. Here is the first. In section 3, when we introduced the philosophical distinction between intentional content and representational vehicle, we remarked that the same intentional content could be carried by two different representational vehicles. Next, we suggested that a representational vehicle with a static structure is as capable of carrying the same tensed content as a representational vehicle with a dynamic structure. But a case could be made to the effect that representations with dynamic structures carry more information than representations with static structures—akin to the claim that analog representations carry more information that their digital equivalents (Dretske, 1981). If this is the case, then the content of a dynamic representation will always differ, however slightly, from the content of a correspondent static representation. And if so, it is still possible that it is something about the content of a representation typically deployed in a dynamic structure, rather than something about the structure per se, that accounts for the common activation of the core brain network during the mental simulations reviewed earlier. Perhaps—to give an example close to the current literature—it is only self-referential, goal-oriented, and subjectively plausible hypothetical simulations that tend to be deployed in dynamic structures and, as such, only these recruit the core brain network.

Whether or not there is one unique kind of content that recruits the core brain network is, of course, an empirical question. Indeed, it seems to be the question leading a lot of the research on the cognitive neuroscience of mental simulation. For instance, noticing the similarities in brain activation between past and future thinking, on the one hand, and theory of mind, navigation, and moral cognition, on the other, Buckner and Carroll (2007) suggested that since all these processes had in common an element of self-projection, then the deployment of mental representations with a self-projection content may account for the common activation of the core brain network. But there are a number of results that are difficult to fit with this hypothesis, as they suggest not only that critical regions of the core brain network may not be necessary for certain tasks that involve self-projection (e.g., temporal discounting or regret anticipation; Craver et al., 2014) but also that they may not be sufficient (e.g., counterfactual thoughts involving others and not oneself; De Brigard et al., 2015). So the strategy has been to refine the hypothesis in order to exclude those contents that may not recruit the core brain network, and to try to come up with a characterization of a particular kind of content that can effectively capture those and only those representations that do recruit it. In the long run this strategy may work, but we worry that it could involve resorting to such a gerrymandered content description that its explanatory and predictive values might diminish. In this sense, exploring the simpler hypothesis that what unifies these common activations is something about the structure of the simulation, rather than their content, may be more beneficial both practically and theoretically.

The second objection is related to the first. As mentioned, the distinction between content and vehicle demands the possibility of sameness of content with only a difference in vehicle. However, if content is understood as the information carried by the representation, and there is a difference in the information carried by a dynamic versus a static representation, then there is a difference in content and not merely a difference in vehicle. But, if so, it is perfectly possible that the dynamicity of a mental representation may *not* be a property of the representational vehicle but rather of the intentional content, in which case the orthogonality between these two dimensions (see Figure 8.2) would be questionable. This is an important objection, but it may ultimately be terminological. For one, if we restrict the notion of representational vehicle to the *physical* substrate of the representation, then by fiat we would be ruling out the possibility of vehicles differing in dynamic, as opposed to physical, properties. This may force us to have to capture the distinction between dynamic and non-dynamic representations at the level of intentional content, which—again—is often understood as the information carried by a mental representation. However, such a notion of content is still somewhat vague, as it comprises both informational message and informational format. Our sense is that a broader definition of representational content in terms of carried information may still allow us to draw a distinction between contents that carry either temporal or non-temporal information in more or less dynamic formats. If so, then, the dynamic/non-dynamic distinction we draw here will re-emerge, albeit as a feature of the content of the representation, rather than the vehicle. Indeed, one of the motivations for us to talk about dynamic *structures* rather than dynamic *vehicles* is that we want to allow for the possibility that the two-way contrast between static/dynamic versus temporal/non-temporal representations may eventually be better captured by an adequate theory of the contents of mental simulations. We take this objection, then, as an invitation for further philosophical research on the notion of intentional content as it applies to MTT representations.

A third objection challenges the claim that there is such a thing as a static representation. After all, every mental content presumably takes some time to be consciously experienced by a subject, however fleetingly. Even entertaining a brief sentence in one's mind, such as "Washington, D.C., is the capital of the United States," or a quick image of a single object, like a pair of scissors, is a process that presumably requires at least a few milliseconds. As such, if even the prototypical examples of allegedly static representations take some time to unfold, then they are actually dynamic, in which case the dynamic/static distinction loses its grip. This is a fair point, and we certainly agree (perhaps *contra* the philosophical tradition in analytic philosophy) that even the shortest-lived of our consciously experienced mental contents may require some time to unfold. Nonetheless, this does not invalidate the static/dynamic distinction drawn here, as we do not think of it as a dichotomous distinction that exhaustively splits every mental state into either static or dynamic. Instead, our view is that every mental content falls somewhere in a continuum of structural dynamicity, with some contents close to being fully static, and some being extremely dynamic—even if there are not specific instances of mental representations that are fully static or fully dynamic. What these extremes may be is indeed a puzzling empirical question, the answer of which may involve understanding the informational limits of internal attention and working memory (De Brigard, 2011), as well as the differences in entertaining simulations in different modalities. Indeed, an attractive question that arises from the dynamic-structure view is whether or not simulations in diverse modalities differentially engage the default network. Would entertaining a dynamic mental narrative in a purely linguistic format, devoid of any visual or auditory elements, be sufficient to engage the default network? Future experiments comparing dynamic representation with linguistic versus non-linguistic formats may be able to tell whether or not the structural dynamicity of the representation is sufficient to engage the default network.

Which brings us to the last point: Are we implying that the function of the default network is to generate and maintain representations with a dynamic structure? After all, some of the most recent proposals about the function of the default network seem to try to define its function by way of characterizing some kind of representational content that is uniquely associated with its engagement, such as socially relevant hypothetical thinking (De Brigard et al., 2014) or self-generated goal-oriented thoughts (Andrews-Hanna et al., 2014). Our view is that the evidence is insufficient, at this point, to be able to adjudicate between competing views, and more research is needed to understand not only what is the best way to characterize the nature of the mental representations supported by the brain's default network, but also what the function of this brain system may be.

What we do believe, however, is that bringing in a hypothesis about the structure of the representation, rather than its content, may contribute to move this research project forward.

ACKNOWLEDGMENTS

This paper was presented at the University of Michigan in Ann Arbor, in August 2015, at the meeting of the Moral Psychology Research Group. We thank the members of the audience for their comments. Special thanks to John Doris, Edouard Machery, Chandra Sripada, and Walter Sinnott-Armstrong for their insightful challenges and suggestions.

NOTES

1. Not everyone who endorses the claim that the common engagement of the neural substrates of episodic memory and future thinking evidences a single system for MTT *also* endorses explicitly the claim that what accounts for this common engagement is the fact that the contents of the mental simulations are tensed. But to many, this assumption looms large, and only now is it starting to be scrutinized (Schacter et al., 2012). Our intention is to bring this assumption to the forefront and discuss it.
2. Another study that sometimes is referenced in relation to lack of hippocampal activity during MTT tasks was conducted by Nyberg and colleagues (2010). In this study, participants were asked either to imagine walking on a familiar path in a possible past, a possible future, or the present, or to remember a specific instance in which they actually walked that path. In an attempt to isolate brain regions differentially involved in MTT, the authors contrasted the temporal conditions against the present condition, and found no hippocampal activity. Nyberg and colleagues interpret this null finding as evidence that the hippocampus may be involved more in the episodic information rather than the temporal aspect of the simulation. In our view, this result is difficult to interpret for methodological reasons. For one, this study is severely underpowered. They recruited only five participants, and reported that not all of them were successful at training. The final number of participants scanned is not reported. In addition, there are only 20 observations per participant for five different conditions, the fMRI data of which was then fit to an analysis of variance model. As a result, it is likely that these null results are simply due to this study being severely underpowered. Given our methodological qualms with this particular study, we mention it only in a footnote rather than in the main text. Further studies may be able to confirm these observations.
3. This observation isn't new, but is worth repeating. William James's famous allegory of the "stream of consciousness" was primarily a criticism against Hume's "train of thoughts" for very similar reasons (James, 1890). The tradition in phenomenology, starting from Husserl (1913), also rejects the view of experiential contents as being discrete and discontinuous with the rest of our conscious experience.
4. Paraphrasing Wittgenstein (1953, 54), if we think of a man climbing a mountain, we don't find the entertained mental representation to be ambiguous with that of

a man descending the same mountain backward. The dynamical nature of these kinds of representations eliminates potential referential ambiguities.

5. The example here suggests that there may be a difference in content as well, and a case could be made to the effect that the representation in panel B carries information that the representation in A does not. This is indeed an important observation with relevant consequences for the forthcoming discussion. As such, it will be considered in section 5.

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