The role of the hippocampus and prefrontal cortex in imagining the future – insights from studies of patients with focal brain lesions

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Abstract

This article focuses on the neural and cognitive component processes that support the ability to imagine the future (episodic future thinking), which has recently been assumed to rely on the reconstructive nature of the episodic memory system. Functional neuroimaging studies have demonstrated the presence of a common core network, which underlies autobiographical remembering and future thinking. This network includes many regions traditionally associated with memory, such as the hippocampus and areas in the prefrontal cortex. However, inconsistent findings have emerged from recent studies of episodic future thinking in patients with amnesia and hippocampal damage, suggesting that imagining the future may not be entirely dependent on this structure. The existing evidence for impairments in future thinking in patients with prefrontal damage is at best either indirect, coming from studies of impaired planning and decision making, or rest on a few case reports. Thus, the precise role of the hippocampus and prefrontal cortex in future thinking remains an open question. In this review, I consider findings from studies of patients with focal brain lesions with respect to current theoretical accounts for different component processes supporting the ability to envision the future and discuss the discrepant results within the literature.

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Introduction

What would it be like to be caught in the present, unable to remember anything from the past or learn anything new, to be lost in time, with no sense of one's past or one's future? This is precisely what happened to English musician Clive Wearing, one of the most famous cases of extreme amnesia ever known. In 1985, Clive, at the time an eminent conductor and music expert in his mid-forties, contracted the herpes simplex virus. The virus completely destroyed his hippocampus bilaterally, leaving him profoundly amnesic. The nature of his amnesia illustrates the distinction first made by Endel Tulving between episodic memory, which is memories of personally experienced events, and semantic memory, which is memory for generic knowledge about the world (Tulving, 1972). Clive's episodic memory is severely impaired, extending back for virtually the whole of his life; he has no memory of his wedding day or of ever having received a musical education. His semantic memory, on the other hand, has remained relatively preserved, and so has his procedural memory. He has retained a normal vocabulary, he recognizes his wife Deborah, and still recalls how to play the piano and conduct a choir. His anterograde amnesia is profound; he cannot transfer new information or experiences into long-term memory. Clive is as unable to imagine future events as he is to remember past ones, his conscious experience being confined entirely to the present, as captured by his wife in the 2005 book *Forever Today* (Wearing, 2005).

It has long been posited that a close relationship exists between memory and envisioning the future. In 1911 the French philosopher Henri Bergson stated: "It may be said that we have no grasp of the future without an equal and corresponding outlook over the past" (Bergson, 1911/1970, pp. 69-70). Bartlett (1932) noted that remembering is not entirely distinct from imagining or from constructive thinking, but that they are closely connected. Perhaps the best known attempt to link the past and future is Tulving's concept of *mental time travel* (Tulving, 1985, 2002a, 2005). According to Tulving, remembering past experiences and imagining future ones are linked because

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they both depend on the episodic memory system, which allows one to draw one's attention from the immediate present to re-experience personal past events, as well as to imagine possible future events in which one might participate (Tulving, 1983).

In recent years, researchers have begun to approach episodic memory within this broader context, considering its involvement in the ability to imagine possible future experiences (Suddendorf & Coballis, 1997; Wheeler, Stuss, & Tulving, 1997). Like memories of past experiences, envisioning the future can be episodic in nature, representing specific experiences in a particular spatiotemporal context. For instance, if you think about your plans for the upcoming weekend, it is likely that an image will appear in your mind's eye. You might see yourself in a different place, with different people, feeling and acting differently, than in the setting you're presently in. Unlike Clive Wearing, we often have such images and thoughts about the future, and these are likely to serve a variety of important and adaptive functions, such as planning, decision-making and emotion-regulation (D'Argembeau, Renaud & Van der Linden, 2011).

The idea that the ability to contemplate the future is necessarily linked with remembering the past has been supported by neuroimaging research, revealing a striking similarity in the neural activity when subjects are asked to imagine possible future experiences and call to mind specific experiences from their personal past (Addis, Wong & Schacter, 2007; Botzung, Denkova & Manning, 2008; Okuda et al., 2003; Spzunar, Watson & McDermott, 2007). This *core network* (Schacter & Addis, 2007) of brain regions consistently activated across studies includes the medial temporal and medial prefrontal cortices, as well as more posterior regions including the retrosplenial and posterior cingulate cortices, which are known to play an important role in autobiographical memory (Cabeza & St. Jacques, 2007; Daselaar et al., 2008; Greenberg & Rubin, 2003; Greenberg et al, 2005; Maguire, 2001; Svoboda, McKinnon & Levine, 2006). The fact that episodic future thinking engages these cortical regions in a similar manner as remembering suggests that common neural and cognitive processes are involved as people envision their future and remember their past (Buckner & Carroll, 2007; Hassabis & Maguire, 2007; Schacter & Addis, 2007; Spreng, Mar & Kim, 2009; Szpunar, Chan & McDermott, 2009). These findings have led to the suggestion that the primary function of the episodic memory system is to provide the building blocks, from which to construct future scenarios (Schacter & Addis, 2007; Suddendorf & Coballis, 1997; 2007). Along these lines the *constructive episodic simulation hypothesis* was advanced by Schacter and Addis (2007; 2009), which holds that the constructive nature of episodic memory (Bartlett, 1932) allows one to draw on the past and flexibly extract and recombine elements of previous experiences to generate novel scenarios (for related views see Suddendorf & Corballis, 1997, 2007). An alternative proposal by Hassabis and Maguire (2007, 2009) posits that episodic memory and imagination are underpinned by a common core process – the ability to construct complex spatial contexts or scenes, thereby emphasizing the visual-spatial aspects of event construction.

The engagement of this common neural network leads to the prediction that compromise of this network should result not only in deficits in remembering, but also in an inability to imagine the future. So far research has primarily focused on the contribution of the hippocampus to episodic future thinking and what happens when this structure is damaged or destroyed. While it has been firmly established that a functional hippocampus is necessary for the retrieval of episodic autobiographical memories (Moscovitch et al., 2005; for a different view see Bayley, Hopkins & Squire, 2006), the evidence is less clear when it comes to episodic future thinking. While some studies of patients with hippocampal damage have documented episodic memory deficits to be accompanied by similar deficits in imagining the future (Hassabis, Kumaran, Vann & Maguire, 2007; Andelman, Hoofien, Goldberg, Aizenstein & Neufeld, 2010; Race, Keane &Verfaellie, 2011), other studies do not report future thinking difficulties in such patients (Cooper, Vargha-

Khadem, Gadian & Maguire, 2011; Maguire, Vargha-Khadem & Hassabis, 2010; Squire et al., 2010), indicating that imagining the future may not be entirely dependent on the hippocampus.

Although functional imaging shows equivalent activation in most brain areas when people engage in past and future event construction, the frontopolar regions and the hippocampus show greater activation when people imagine future events compared with remembering past events (Okuda et al., 2003; Addis et al., 2007). This raises the question of what is unique about envisioning the future that recruits these areas as compared to remembering the past. It may be that imagining the future requires more intensive or even additional cognitive processing, because future events have not yet happened and therefore needs to be constructed from scratch, whereas past events involves retrieval of already established memory traces. However, knowledge of the specific component processes that underlies this more intensive processing is scarce. Schacter and Addis (2007) suggested that whereas both remembering and imagining involve retrieval of information from memory, only the latter requires that details are flexibly *recombined* into a novel event. They argue that this recombination places higher demands on constructive processes and therefore leads to stronger hippocampal involvement due to this structure's role in relational memory processes (Cohen & Eichenbaum, 1993). However, imagining future events also requires a process not shared by remembering, that is, the recombination of elements into truly *novel* events, which is likely to rely on a number of executive processes mediated by the prefrontal cortex (Weiler, Sucham, Koch, Schwarz & Daum, 2011). The prefrontal cortex has also been implicated in other component processes, such as subjective sense of time and motivational aspects of future thinking. Tulving put forth a strong case for prefrontal involvement in the awareness of one's protracted existence across time, what he termed *autonoetic consciousness* (Tulving, 1985, 2002b, 2005; Wheeler, Stuss & Tulving, 1997). Others have pointed to the role of the ventro-medial prefrontal cortex (vmPFC) in attaching self-relevance and value to imagined future events (D'Argembeau, 2011). If episodic future thinking, or more generally the ability to imagine novel scenes indeed relies on component processes supported by the prefrontal cortex, then the ability to engage in future thinking should be affected by damage to these structures. However, only a few studies have directly assessed future thinking after prefrontal lesions.

Studies of patients with focal brain lesions can provide unique insights into brain functioning. Although functional neuroimaging typically reveals activity in distributed brain regions that are *involved* in episodic future thinking, focal lesion studies can inform as to which of these regions are *necessary* for specific cognitive processes. The main purpose of this paper is to review the existing neuropsychological evidence (see Table 1) with respect to the role of the hippocampus and prefrontal cortex in imagining the future. The review will focus exclusively on studies of human subjects, although relevant work has also been conducted with non-human animals (for review see Cheke & Clayton, 2010). The paper is structured so that, first, studies of episodic future thinking after damage to the hippocampus are considered, specifically with regard to this structures involvement in accessing episodic details and in reconstructive processes. The inconsistent findings within the literature are discussed and suggestions are made as to how these can inform our knowledge of hippocampal involvement in event construction. I then consider evidence for a role of the prefrontal cortex in different component processes of episodic future thinking; that is, in the subjective sense of time, in motivational aspects of future thinking and in executive processes involved in the re-combination of elements to construct novel events.

Note that although the focus of the review is to consider findings from studies of patients with focal brain lesion to advance our understanding of the particular contribution of each of these regions to future thinking, numerous neuroimaging studies have also shed light on the topic and such data will be considered when appropriate. Throughout the paper, the concepts of "imagination", "imagining the future", "episodic future thinking" and "envisioning the future" will be used in a roughly interchangeable manner, referring to the ability to mentally construct hypothetical events or scenarios.

The hippocampus and imagining the future

Several recent reviews have elaborated on the possible role of the hippocampus in imagining the future (Addis & Schacter, 2012; Buckner, 2010; Hassabis & Maguire, 2009), the general idea being that to generate potential future scenarios one must draw upon information from semantic and episodic memory, and recombine this information into a coherent mental representation of a novel event. The hippocampus is known to play a pivotal role in autobiographical memory (Scoville & Milner, 1957), which has spurred extensive research into its potential role in imagining future and fictitious events (Hassabis & Maguire, 2007, 2009; Addis & Schacter, 2012).

Access to episodic memory details – the building blocks for future event construction

The idea that access to memory details may be necessary for imagining the future comes from neuropsychological studies of patients with amnesia. Early observations of patients with memory loss have provided anecdotal evidence of deficits in the ability to envision the future. In his seminal paper on Korsakoff's syndrome, Talland (1965) noted patients' inability to formulate future plans and the fact that questions about the personal future were only answered with generalities (Buckner, 2010). More recently, similar deficits were described in the famous patient H.M., who became densely amnesic following bilateral resection of the hippocampus and related medial temporal lobe (MTL) structures (Corkin, 2002; Scoville & Milner, 1957). H.M. did not make predictions about future personal events, and when asked to do so; he either reported events from the distant past or simply did not respond (Buckner, 2010). Tulving (1985) explicitly hypothesized a close link between episodic memory and future thinking, on the basis of his observations of patient K.C., who developed severe anterograde amnesia as a result of a head injury causing MTL damage. K.C.'s retrograde amnesia showed a sharp dissociation between episodic memory and semantic memory. A good deal of his general knowledge of the world, including knowledge about himself, was preserved, but he was incapable of recollecting any personally experienced events. Tulving noted that K.C. was as unable to imagine his personal future as to remember his past (Tulving, 1985, 2002a). In a more recent examination of his deficits, Rosenbaum, et al. (2009) observed that K.C.'s impairment extended to the construction of fictional events, suggesting that the temporal component of future imagining might not be as crucial as the (re)constructive element.

Klein, Loftus and Kihlstrom (2002) documented similar difficulties in another amnesic patient, D.B., who suffered brain damage following cardiac arrest. D.B. could not remember his personal past or imagine possible experiences in the future. In contrast to his profound episodic impairment, D.B.'s semantic memory of facts about public figures and events was intact, and he was able to anticipate future issues and events in the public domain. However, Klein, Loftus and Kihlstrom (2002) only examined relatively abstract public scenarios (e.g. environmental challenges in the future), and although not discussed by the authors, this leaves open the possibility that D.B.'s deficits involved more general problems constructing *specific* scenes (personal and non-personal). In both K.C.'s and D.B.'s case, there is a lack of knowledge of the neuroanatomical damage beyond the hippocampus. Tulving's patient K.C. had extensive brain damage, including lesions in the occipital and prefrontal lobes (Rosenbaum et al., 2005). No neuroanatomical findings were reported for D.B., though the hippocampus tends to be particularly sensitive to damage and cell loss due to ischemia. This makes it difficult to hypothesize which brain regions were responsible for the co-occurring deficits or even if the same brain regions were responsible in both cases. Nevertheless the studies described above make a strong case for a link between episodic memory and future thinking, indicating that access to episodic details is an important or even necessary condition for the construction of future and fictional events.

More recently, Hassabis et al. (2007) examined the ability to imagine novel scenarios in five patients with documented bilateral hippocampal amnesia. Like the patients K.C. and D.B., these patients had retained premorbid semantic memory, but were severely amnesic of personal past experiences. Participants were instructed to imagine and describe novel scenes such as "Imagine you are lying on a white sandy beach in a beautiful tropical bay". Event descriptions were scored based on content, spatial coherence and subjective qualities of the imagined scenes. Relative to healthy controls, the patients' descriptions lacked details and were deficient in terms of spatial coherence. The authors suggested that both remembering and the ability to imagine novel scenarios rely on an intact hippocampus, which flexibly combines elements from memory into a coherent scene (Hassabis & Maguire, 2007). This claim was further supported by findings, that one of the patients (P01), who had some residual hippocampal functioning, was able to generate rich and coherent scenes comparable to those of controls despite being profoundly amnesic. However, this patients spared scene construction also suggests that intact episodic retrieval capabilities are not a necessary prerequisite for imagining new experiences (Hassabis et al., 2007). Although Hassabis et al. (2007) stated that their patients were selected on the basis of lesions restricted to the hippocampus, Squire et al. (2010) noted that four of the five patients became amnesic as a result of limbic encephalitis, which typically presents with brain abnormalities extending beyond the MTL. They argued that the one patient who was not impaired in scene construction had brain damage as a result of a different etiology (meningeoencephalitis) as well as residual hippocampal tissue.

In direct contradiction to Hassabis et al.'s (2007) findings, Squire et al. (2010) reported preserved future event construction in six patients with bilateral damage restricted to the hippocampus, thereby challenging the view that hippocampal damage is sufficient for impaired future thinking. However, although these patients had hippocampal lesions, their ability to recall autobiographical episodes from the remote past was preserved and they were only modestly impaired on recent memory. The fact that, in contrast to prior studies, these patients did not demonstrate pervasive retrograde amnesia touches on an unresolved debate regarding the time course of hippocampal involvement in the storage and retrieval of remote episodic memories. A key point of contention within the memory literature is whether memories ever become completely independent of the hippocampus, and can be autonomously supported by the cortex, as put forward by Squire and colleagues (Squire & Alzarez, 1995; Bayley et al, 2006; Kirwan, Bayley, Galván & Squire, 2008), or whether retrieval of contextually rich memories always remain dependent on the hippocampus (Nadel & Moscovitch, 1997; Nadel, Samsonovich, Ryan & Moscovitch, 2000). According to the first view, an intact hippocampus should not be *necessary* for envisioning the future, since one would still be able to access detailed memories from the remote past.

This issue was addressed by Race et al. (2011), who examined the ability to construct detailed narratives of past and future events with different temporal distance to the present in eight amnesic patients with MTL lesions. They showed that patients' memory and future thinking were impaired relative to controls on all time periods assessed, in accordance with episodic memories continued dependence on the hippocampus. Importantly, one of the patients (P05) who had damage confined to the right hippocampus presented future thinking impairments that mirrored that of the other patients who had additional extra-hippocampal damage, supporting the notion that damage to the hippocampus is *sufficient* to cause impairments in episodic future thinking, contrary to the view advanced by Squire et al. (2010).

Maguire and Hassabis (2011) noted that different methodologies may provide some explanation as to why patients' performance appears to be spared in the Squire et al. (2010) study. In most studies of episodic memory and future thinking in amnesia, patients have been required to construct specific, pre-determined events (e.g., "lying on a sandy beach"), while in the Squire et al. (2010) study, patients were provided with single word cues (e.g., "tree") and were not confined by having to describe events related to the cue. This lack of constraints on subject responses may have enabled the patient to (re)construct past and future events based on already established scripts in semantic memory, which do not place as high demands on hippocampal-mediated processes. This is in accordance with findings that semantic information can be retrieved independently of the hippocampus (Steinvorth, Levine, & Corkin, 2005; Leyhe, Müller, Eschweiler, & Saur, 2010), and that this structure is more strongly engaged when people imagine specific versus general future events (Addis, Cheng, Roberts & Schacter, 2011).

Spared imagination in the context of severe amnesia has also been reported in patients with developmental amnesia, however, challenging the notion that future thinking relies on episodic memory. Maguire et al. (2010) found that one patient, Jon, who had sustained hippocampal damage early in life, was able to construct fictional and future experiences. Similarly, Cooper et al. (2011) reported that a group of developmental amnesic children were able to construct fictional scenes, despite being impaired at recalling past events. Interestingly, both Jon and the previously described patient P01 (Hassabis et al., 2007) showed activation of residual hippocampal tissues during fMRI, suggesting that some retained hippocampal functioning may be sufficient to support scene construction. The authors suggested that in the case of developmental amnesia, where hippocampal pathology is incurred early in life, some functional sparing or neural plasticity/functional reorganization may be sufficient to support scene construction, but not enough for accurate and detailed autobiographical memory.

In their review, Addis and Schacter (2012) noted that all findings of intact future thinking in amnesic patients have emerged using some version of the scene construction task (Hassabis et al., 2007). According to Hassabis et al. (2007) this task was designed to increase the dependence of constructions on semantic memory, because the cues (e.g. "Imagine you are lying on a white sandy beach") are likely to elicit more generic scenes. So it may be that this particular task enables patients to construct scenes on the basis of details from semantic memory of what a beach looks like, rather than on details from their own memories. Interestingly, using different methodologies, two studies reported contrary findings examining the same patient, H.C., with developmental amnesia. While Kwan, Carson, Addis and Rosenbaum (2010) found parallel impairments for both past and future event generation in H.C. using the adapted Autobiographical Interview (Addis et al., 2007), Hurley, Maguire and Vargha-Khadem (2011) reported intact constructive abilities using the scene construction task.

These inconsistencies highlight a broader methodological challenge. Despite the fact that episodic and semantic memory can be impaired independently of each other, they are closely intertwined when it comes to our everyday memories. Autobiographical memories are constructed from episodic details, as well as more personal and cultural semantic knowledge (Berntsen & Rubin, 2004; Conway & Pleydell-Pearce, 2000). Similarly, when we imagine possible future events, we also to a large extent draw on culturally acquired knowledge of what and when something is likely to happen (Anderson & Dewhurst, 2009; Schacter, Addis & Buckner, 2008; Suddendorf & Corballis, 2007; Szpunar, 2010), and narrative accounts of episodic memories and future thoughts contain both episodic and semantic details (Levine, Svoboda, Hay, Winocur & Moscovitch, 2002; Addis, Wong & Schacter, 2008). Semantic memory is often preserved in patients with amnesia, as indicated by a reduction in episodic but not semantic details when such patients generate past and future event descriptions (Race et al., 2011), and the fact that D.B. in spite of severe episodic memory deficits was able to predict possible future outcomes in the public domain requiring more abstract knowledge (Klein et al., 2002). The reason that patients with developmental amnesia show preserved imagination on the scene construction task might be that this task is less sensitive to episodic memory impairments, the patients relying on semantic memory as a compensatory strategy (which might be more developed when amnesia occurs early in life).

Such compensatory strategies in the form of higher reliance on semantic information have previously been reported in older adults (Addis et al., 2008).

Overall it seems clear that there are some cases in which hippocampal damage differentially affects memory and future thinking, but it is not well understood why differential deficits are observed in some cases while parallel deficits are observed in others. The debate as to whether access to episodic details is *necessary* for envisaging new experiences remains to be settled. However, another question is whether access to episodic details is *sufficient* for future thinking, or whether future thinking employs additional processes.

Detail recombination and scene construction

Although most neuroimaging studies so far have been interested in the commonalities between episodic memory and episodic future thinking, some differences have emerged from the literature as well. While most areas show equivalent activation to past and future event generation, when differences are observed, future events are typically associated with additional neural activity. Among the regions that have been identified to show this pattern of activation are areas in the anterior portion of the hippocampus (Addis et al., 2007). Addis, Pan, Vu, Laiser and Schacter (2009) suggested that future thinking places higher demands on relational processes when having to *re-combine* bits of information from different events into coherent scenes, and therefore leads to stronger hippocampal engagement. This proposal was based on findings that the anterior portion of the hippocampus appears to be important for relational memory processes (Cohen & Eichenbaum, 1993), particularly when having to integrate details from memories formed in different spatio-temporal contexts (Staresina & Davachi, 2009). In accordance with this, Addis and Schacter (2008) reported common neural activation to details of past and future events in the posterior portion of the hippocampus, while the anterior portion was responsive only to the number of details comprising future events. More recently, the same researchers demonstrated increased activity in the right anterior hippocampus when constructing specific events, relative to more generalized future events (Addis et al., 2011), suggesting that the right anterior portion of the hippocampus plays an important role when having to construct an event that is both detailed and novel.

Hassabis and Maguire (2007) advanced a related, though distinct hypothesis proposing that the hippocampus facilitates the construction of complex and coherent scenes. Contrary to the theory put forward by Schacter and Addis (2007), Hassabis and Maguire (2007) argue that component elements of event constructions are not merely fragments of past events; rather, they also comprise elements that are more abstract and semantic. Referring to their finding that both future and fictitious scenes constructed by patients with hippocampal amnesia not only lacked content, but were particularly deficient in terms of spatial coherence, they point to the outstanding role of the hippocampus in promoting *scene construction*, arguing that this process is critically involved in both autobiographical memory and imagination. Given that research has shown that the posterior hippocampus is particularly important for the processing of spatial relations and storing of cognitive maps (Hassabis et al., 2009; Maguire et al., 2000; Ryan, Lin, Ketcham & Nadel, 2010), the importance of this area in event construction may be to provide a spatiotemporal context or environmental setting into which events can be bound (Byrne, Becker & Burgess, 2007).

Hippocampal involvement in detail recombining or scene construction is seemingly at odds with the findings by Squire et al. (2010) of intact future event construction in amnesic patients with bilateral hippocampal damage. These patients could imagine the future and had relatively preserved autobiographical memory, suggesting that access to episodic details may be sufficient for episodic future thinking.

In contrast, Andelman et al. (2010) reported of a young patient whose lesion was limited to the hippocampus bilaterally, and who lost access to her autobiographical memory extending back three years. This patient had more than 20 years of memories to draw from when having to imagine the future. However, she was completely unable to do so, indicating that while access to episodic memory might be necessary, some additional processes are involved in future thinking. Although impaired detail integration and lack of spatial coherence was reported by Hassabis et al. (2007), most studies have not included such measures, making it difficult to determine whether detail recombining and scene construction are affected in patients with hippocampal amnesia. The observation that patient P01 (Hassabis et al., 2007) and Jon (Maguire et al., 2010) both had spared right hippocampal functioning and were unimpaired on scene construction tasks despite being densely amnesic, indicates that, in line with the neuroimagine literature, the anterior right hippocampus is a key area in serving scene construction (Addis et al., 2007, 2011; Addis & Schacter, 2008). On these grounds, Hassabis et al. (2007) concluded that while intact scene construction might be necessary for autobiographical memory, it is not sufficient. However, the findings of intact autobiographical memory and impaired future thinking by Andelman et al. (2010) seem to contradict the idea that autobiographical memory relies on intact scene construction.

Considering the reviewed studies together, it seems clear that the hippocampus is critically involved in the construction of future and fictitious scenes. Evidence suggests that this involvement may at least be twofold. First, the hippocampus is necessary for accessing episodic details from memory, which can be used to furnish constructed novel events. Second, the recombination and integration of these details into coherent scenes also rely on the hippocampus. It may be that different subfields are engaged in these two processes. Studies indicate that while some regions in the right anterior hippocampus are more involved in detail recombining and novel scene construction, other more posterior regions of the hippocampus are required for episodic retrieval. While this hypothesis needs to be examined further, it may provide some insight into the seemingly contradictory findings reported. It may be that in some cases lesions affect both of these processes, while in other cases leaving one or the other relatively spared. The studies of developmental amnesia further call into question whether access to episodic details is necessary for coherent scene construction, which may be performed by relying on semantic information. Thus, it may be that an intact hippocampus is critical when it comes to the construction of event representations that are detailed and specific, however, much less is known about hippocampal involvement in semantic future thinking.

Prefrontal lobe contributions to future thinking

In 1979 the Swedish brain physiologist David Ingvar described studies in which he observed increased prefrontal lobe activity during resting states where participant sat quietly with their eyes closed. Ingvar interpreted this activity as reflecting an internal connection between the past and the future: 'On the basis of previous experiences, represented in memories, the brain - one's mind - is automatically busy with extrapolation of future events and, as it appears, constructing alternative hypothetical behavior patterns in order to be ready for what may happen'(p. 21). Ingvar suggested that the prefrontal cortex constitutes the anatomical basis for "memory for the future", and argued that this region plays a crucial role in planning and foresight (Ingvar, 1985). Ingvar's assumption is in accordance with decades-old observations that frontal lobe damage is associated with a lack of account for the future, inclining patients to 'live in the here and now' (Ackerley, 1950/2000). Such observations suggest a possible role of this region in future thinking. However, future thinking is likely to rely on multiple component processes and the frontal lobes are not a homogeneous entity. Here, I review evidence for frontal involvement in future thinking with respect to three components: awareness of one's protracted existence in time, motivational aspects of future event representations and executive functions.

Awareness of one's protracted existence across time

Of fundamental importance for the ability to envision the future, one must first be aware that one's self will continue to exist in the future. Almost at the same time as Ingvar made his observations, Tulving proposed that the capacity to be consciously aware of one's continued temporal existence from the past, the present and to the future reflects the functioning of a special kind of awareness, which he termed *autonoetic consciousness* (Tulving, 1985, 2005; Wheeler et al., 1997). Tulving argued that autonoetic (self-knowing) consciousness is fundamentally different from other kinds of conscious awareness which underlies the capacity to *know* that the past and the future exist, the same way we know other facts about the world. The latter he termed noetic (knowing) consciousness. Only autonoesis is thought to bear a personally meaningful relation to time, and makes thinking about subjective time possible. Evidence for this distinction come from the patient cases K.C. and D.B. described earlier, who were not *conscious of* their personal past or their personal future (Tulving, 1985; Wheeler et al., 1997). Both of these patients had no difficulties understanding the concept of time, as they could tell time, and knew that there is a past and a future, but what they lacked was the awareness that their current self extends into a personal past or personal future (Tulving, 2002b). Autonoesis has been seen as critically dependent on the prefrontal cortex (Wheeler et al., 1997). This supposition has received some suggestive evidence from two case studies.

First, Levine et al. (1998) described patient M.L., a young man who after a traumatic brain injury suffered damage to the right ventral frontal cortex including the uncinate fasciculus, a band of fibers connecting prefrontal and temporal cortical regions. As a result of his injury, M.L. developed severe isolated retrograde amnesia for both episodic and semantic information. Because M.L. had not lost his ability to acquire new semantic information, he was able to re-learn much semantic knowledge, including facts about his life pre-dating the injury. But he could not autonoetically recollect any past experiences. M.L.'s impaired autonoetic awareness also manifested itself in terms of a lack of account for the future. M.L. had difficulties with self-regulation and demonstrated a lack of awareness of his self's continued existence in the future, his behavior being driven by semantic knowledge of how one should behave, rather than by goals and intention rising from his own identity.

Similarly, Stuss (1991) described patient R., who after the removal of a tumor in the right prefrontal cortex, exhibited impaired self-awareness. Despite an impressive amount of self-knowledge, R. could not use this knowledge to behave appropriately in the present or make appropriate plans for the future. Thus, autonoetic awareness may not only be a prerequisite for episodic future thinking, but for all activities that require an individual to appreciate that a particular personal experience may occur in the future (Tulving, 2002b).

In a related line of research, Fellows and Farah (2005) examined the effect of dorsolateral and ventromedial frontal lobe damage (vmPFC) on future time perspective (e.g. a measure of the length of an individual's self-defined future). They found that future time perspective was selectively foreshortened following damage to the ventromedial, but not dorsolateral, frontal lobes. This indicates that the vmPFC is involved in the capacity to anticipate more distant future events, which allows one to decide and act according to long-term plans and goals rather than immediate circumstances. The foreshortened timeframe with which vmPFC patients consider themselves in the future may therefore contribute to the impairments in decision-making and planning often reported in such patient.

Rasmussen and Berntsen (in press) examined episodic future thinking in a group of patient suffering from traumatic brain injury, and found that these patients not only were impaired in recalling and imagining specific past and future events compared to healthy controls, but that the patients presented even more pronounced difficulties in episodic event representations when having to recall or imagine distant events, indicating that mental time travel into the distant past or future is somehow cognitively more demanding. These patients presented impaired executive functioning, suggesting that frontal lobe dysfunction might partly explained these difficulties.

Attaching self-relevance and value to imagined future events

When contemplating our personal future, we often focus on a particular goal we would like to attain, or a particular situation we would rather avoid (Berntsen & Jacobsen, 2008; D'Argembeau, 2011; Newby-Clark & Ross, 2003). Thus, imagined future events are often of importance to the self, and endowed with motivational force, which influences our decision-making and actions in adaptive ways (D'Argembeau, 2011).

The fact that patients, like M.L. and R. (Levine et al., 1998; Stuss, 1991), with damage to the prefrontal cortex and in particular to the vmPFC, seem oblivious to the consequences of their actions, and present severely impaired decision-making in their daily life, in marked contrast to their otherwise largely preserved cognitive abilities, has led to the suggestion that the vmPFC is critical for attaching affective/emotional signals to mental representations of future outcomes. Thereby enabling the individual to know 'what it feels like' to be in a given future situation, and thus guide decision-making (Bechara & Damasio, 2005; Bechara, Damasio, & Damasio, 2000; Damasio, 1994). Bechara and Damasio (2005) suggested that the anterior vmPFC may be particularly important for representing distant future outcomes. This is supported by neuroimaging studies showing that the anterior vmPFC is more active when people imagine emotional events in the distant than in the near future (D'Argembeau, Xue, Lu, Van der Linden, & Bechara, 2008) and when they imagine personal future events relative to non-personal future events (D'Argembeau, et al., 2010). Moreover, in the latter study the elicited activation in vmPFC when participants imagined personal future events overlapped extensively with a task that explicitly asked participants to make judgments of self-relevance of trait adjectives. These findings suggest that the vmPFC may play an important role in appraising personal relevance or value to imagined future events (D'Argembeau, 2011).

Recent neuroimaging studies have also shown that differences in the way people perceive present versus temporally distant selves are mirrored in vmPFC activity (D'Argembeau et al., 2008; D'Argembeau, et al., 2010). Ersner-Hershfield, Wimmer and Knutson (2009) reported higher vmPFC activation when participants made judgments about present versus future selves. Interestingly, smaller differences in vmPFC activity when thinking about present versus future selves (presumably reflecting the extent to which people feel connected to their future selves) correlated with how steeply people devalued reward as its delivery was pushed into the future, a phenomenon known as temporal discounting. Two recent studies have also shown that when people imagine experiencing a reward in the future, they display an increased tendency to favor rewards that produce greater long-term payoffs, showing that future thinking can impact temporal discounting. Moreover, this effect was mirrored by increased activity in the hippocampus and prefrontal regions (Peters & Büchel, 2010; Benoit, Gilbert & Burgess, 2011). These findings suggest that the vmPFC is critically involved in temporal discounting. However, Fellows and Farah (2005) reported that vmPFC damage did not influence temporal discounting rates, only future time perspective, arguing against a critical role for the vmPFC in the subjective valuing of future rewards.

Executive functions and working with memory

Although memory and future thinking draw on similar component processes, there are also profound differences between the two processes. As noted by Suddendorf (2010) and Weiler, Suchan and Daum (2010), remembering and imagining the future are for one separated by the inherent fact that the future is always uncertain, while we are fairly certain of what happened in the past, and such differences are likely to be reflected in the neural recruitment. As previously mentioned, Schacter and Addis (2007) argued that future thinking places higher demands on constructive processes leading to stronger activation in the hippocampus. Weiler et al. (2011) suggested that imagining novel events also requires a process not shared by remembering, that is the recombination of elements stored in memory to generate a truly *novel* event. While retrieval of past episodes only requires the reactivation of a single memory trace, thereby making remembering possible through associative processes, future thinking is a much more effortful and complex process that requires the individual to recombine bits of information from multiple memory traces to construct novel future events (Anderson & Dewhurst, 2009; Weiler, et al. 2011). This *recombination* is likely to rely on multiple executive control processes mediated by the prefrontal cortex; searching for details stored in memory, evaluating whether these details are feasible to unify into the novel event, and the rejection of some details, which may lead to additional search activities, while simultaneously holding the retrieved details in working memory (Weiler et al, 2011). Although such executive control processes are involved both in episodic memory and episodic future thinking, they are likely to be more strongly engaged in the latter, due to the additional demands. In support of this, Addis et al. (2007) reported that, compared to remembering, future thinking recruited several additional regions including the frontopolar cortex and the left ventrolateral prefrontal cortex, and Smallwood, Nind and O'Connor (2009) demonstrated that mind wandering into the future decreases when prefrontal resources are being otherwise recruited. If imagining novel scenarios involves additional processes not (to the same extent) recruited by episodic memory, then it should be possible to observe selective deficits in future thinking while episodic memory is spared. Reviewing the literature, only two studies of patients with focal brain damage have examined the ability to construct novel events with only mild or no apparent memory deficits.

Berryhill, Picasso, Arnold, Drowos and Olson (2010) examined past and future event construction in two patients with bilateral posterior parietal lesions and in five patients with unilateral prefrontal lesions. While patients with bilateral posterior parietal lesions were impaired on both past and future event construction, patients with prefrontal damage presented spared autobiographical memory but moderate deficits on future event construction. Interestingly, the prefrontal patients who were included as a control group were specifically selected on the basis that their lesions did not affect the vmPFC or other areas known to be involved in memory or construction tasks. The selective impairments in future event construction after lesions to the ventrolateral and dorsal PFC may be attributed to these areas involvement in the ability to effectively access and select elements from memory for working memory manipulation. Thus, damage to these structures may prevent the coherent integration of memory elements to construct novel scenes (Berryhill et al., 2010).

Weiler et al. (2011) also reported differential impairments of remembering and imagining novel events in two patients with lesions in the medial dorsal thalamus. This nucleus of the thalamus is implicated in executive functions and strategic retrieval due to its dense connections with the PFC. The patients' descriptions of novel events lacked content and spatio-temporal details, with these impairments being most prominent for imagined personal fictional and impersonal events, while milder deficits were reported for episodic future thinking. This finding is in accordance with the hypothesis that lesions in brain regions linking prefrontal control processes with medial-temporal lobe memory processes affect the ability to flexibly recombine stored information into novel events.

In a related line of research, de Vito and colleagues (2012) examined future thinking in patients with Parkinson's Disease, and found these patients to be impaired relative to controls on the amount of episodic details generated for future events but not for memories or fictitious events.

These patients presented problems on executive control, while having no difficulties on traditional memory tasks. Here, problems constructing future events could not be attributed to scene construction difficulties, since patients could successfully integrate information into coherent fictitious events. The authors argued that future thinking might be more cognitively costly than event generation in general, because it requires a more monitored and controlled search within memories.

Taken together, these studies suggest that impairments in constructing novel events can occur in the absence of impaired memory, demonstrating some asymmetry between the two processes. However, it is unclear whether this distinction applies to novel event construction more broadly (Weiler et al., 2011) or more specifically to episodic future thinking (de Vito et al., 2012). Future research will be needed to investigate the contribution of different executive sub-components on scene construction.

Future directions

Considering the findings from the patient studies reviewed herein, there appears to be evidence supporting the idea that episodic future thinking relies on several component processes modulated by the hippocampus. When imagining the future, we draw on details retrieved from episodic memory, and these details need to be recombined and integrated into coherent scenes. The evidence suggests that both of these processes depend to some extent on the hippocampus. However, an important question is whether different subfields of the hippocampus are associated with specific component processes. Of interest here is the finding that the one patient (P01) in the Hassabis et al. (2007) study, who could imagine future scenarios, had some spared right anterior hippocampal functioning, while the patient (P05) in the study by Race et al. (2011) who had damage restricted to the right hippocampus was severely impaired on future thinking. These findings indicate that there may be some functional lateralization, the right hippocampus being more involved in reconstructive processes underlying novel event generation, while the left hippocampus appears to be similarly engaged during past and future event construction. To shed light on the role of different areas of the hippocampus, it will be necessary for future studies to employ more refined methods to address whether lesions to different hippocampal subfields influence different component processes of future thinking.

The findings from studies of patients with developmental amnesia raise the question as to how the age of onset of amnesia affects the degree of impairment. Is residual hippocampal tissue sufficient to support scene construction or are these patients simply relying on their semantic knowledge when constructing specific scenes? It may be that when damage occurs early, patients develop other strategies in which access to episodic details is not necessary, but where semantic and more abstract information is sufficient for event construction. However, the relationship between semantic knowledge and event construction remains to be determined. While the focus so far has been on episodic memory, it is important to address other modes in which people can think of the future. As the case of D.B. illustrates, episodic future thinking might be impaired while leaving semantic future thinking spared. It is important for research to address how these different memory systems interact to produce more complex abilities. For example, Berntsen and Jacobsen (2008) suggested that only through the acquisition of semantic cultural-cognitive knowledge structures does it become possible to mentally project one-self forward in time into the distant future.

Reviewing the literature also highlights some methodological concerns, questioning to what extent different results are due to different task requirements. Future studies will be needed to explore the effect of different types of cues on event construction in studies of amnesic patients. Furthermore, scoring procedures should include techniques that parse episodic and semantic information, and assess coherence and detail recombining in event construction.

Although damage to the hippocampus can cause dense amnesia, damage to the prefrontal cortex often leads to more subtle deficits in memory. However, the evidence reviewed here suggests a role of the prefrontal cortex in several component processes involved in future thinking. The vmPFC is likely to play a role in the awareness of one's protracted existence in time and in the capacity to anticipate more distant future events. The same neural structure has also been implicated in motivational aspects of future thinking, that is, in attaching personal relevance and value to imagined future events, which may have important consequences for decision-making.

The studies considered herein also highlight the existence of an asymmetry between episodic memory and future thinking. Weiler et al. (2011) and Berryhill (2010) both showed that impairments in imagining novel events can occur in the absence of detected memory deficits. These impairments are unlikely to be caused by deficits in aspects of self-awareness, or by problems binding and integrating details, since episodic memories also draw on these components. In contrast to patients with hippocampal damage, difficulties seem to arise from impairments in the executive aspects of imagination mediated by prefrontal areas. These findings clearly demonstrate that while episodic memory might be the basis for future thinking, future thinking involves additional processes.

At a more general level, although behavioral and neural differences between memory and future thinking have been established, little attention has been given to the fact that people are never in doubt as to whether an event has in fact happened or not. Confabulation that results from damage to the frontal lobes, particularly to the vmPFC (Gilboa & Moscovitch; 2002) may present an example of a breakdown in the ability to distinguish between these two processes. People who confabulate provide memories that are obviously false or inappropriate for the context of retrieval, without any awareness of their inaccuracy (Gilboa & Verfaellie, 2010). Like episodic future thoughts, confabulations are based on fragments of existing memories and information that are recombined into novel events, however these patients incorrectly consider them to be real memories. Confabulation is generally considered to be the result of damaged executive retrieval processes; although patients can retrieve information, they experience a disturbed sense of temporality or a deficit in the ability to distinguish among different contexts or sources of information, making them unable to retrieve memories in the proper order, at the proper time or in the proper context (Gilboa & Moscovitch, 2002; Moscovitch & Winocur, 2002; Greenberg & Rubin, 2003). Consequently, these patients are incapable of distinguishing between real and imagined events.

Research so far has centered on hippocampal involvement in future thinking. However, the evidence reviewed here suggests that prefrontal lobe contributions may be as important for future thinking as intact hippocampal functioning. This is also likely to be the case for other brain areas. Interactions between frontal and hippocampal systems are important in understanding how future thoughts are constructed and used to guide decisions. While the hippocampus is needed to access details and link together bits of information, these elements are held in working memory. The prefrontal cortex is actively involved in the selection and evaluation of these various elements, so that the constructed event is in fitting with the situational demands. Although much more research is needed to understand the contribution of different areas to episodic future thinking, it is evident that a complex interaction between medial-temporal (memory processes) and prefrontal cortical regions are involved. However, the exact contribution of these areas still needs to be determined.

References

Ackerly, S. (1950/2000). Prefrontal lobes and social development. *Yale Journal of Biology and Medicine*, *73*(1–6), 211–219.

Addis, D.R., Cheng, T., Roberts, R., & Schacter, D.L. (2011). Hippocampal contributions to the episodic simulation of specific and general future events. *Hippocampus*, *21*, 1045-1052

Addis, D.R., Pan, L., Vu, M.A., Laiser, N., & Schacter, D.L. (2009). Constructive episodic simulation of the future and the past: Distinct subsystems of a core brain network mediate imagining and remembering. *Neuropsychologia*, *47*, 2222-2238.

Addis, D. R. & Schacter, D. L. (2008). Effects of detail and temporal distance of past and future events on the engagement of a common neural network. *Hippocampus 18*, 227-237.

Addis, D.R. & Schacter, D.L. (2012). The hippocampus and imagining the future: Where do we stand? *Frontiers in Human Neuroscience, 5*, 173.

Addis, D. R., Wong, A. T. & Schacter, D. L. (2007). Remembering the past and imagining the future: Common and distinct neural substrates during event construction and elaboration. *Neuropsychologia 45*, 1363–1377.

Addis, D. R., Wong, A. T., & Schacter, D. L. (2008). Age-related changes in the episodic simulation of future events. *Psychological Science, 19*, 33–41.

Andelman, F., Hoofien, D., Goldberg, I., Aizenstein, O. & Neufeld, M. Y. (2010). Bilateral hippocampal lesion and a selective impairment of the ability for mental time travel. *Neurocase 16*, 426–435.

Anderson, R. J., & Dewhurst, S. A. (2009). Remembering the past and imagining the future: Differences in event specificity of spontaneously generated thought. *Memory, 17*, 367-373.

Atance, C. M., & O'Neill, D. K. (2001). Episodic future thinking. *TRENDS in Cognitive Sciences, 5*, 533-539.

Bartlett, F.C. (1932). *Remembering: A Study in Experimental and Social Psychology.* Cambridge University Press.

Bayley, P. J., Hopkins, R. O. & Squire, L. R. (2006). The fate of old memories after medial temporal lobe damage. *Journal of Neuroscience, 26*, 13311-13317.

Bechara, A., & Damasio, A. R. (2005). The somatic marker hypothesis: A neural theory of economic decision. *Games and Economic Behavior*, *52*, 336-372.

Bechara, A., Damasio, H., & Damasio, A. R. (2000). Emotion, decision making and the orbitofrontal cortex. *Cerebral Cortex*, *10,* 295–307.

Benoit, R. G., Gilbert, S. J. & Burgess, P. W. (2011). A neural mechanism mediating the impact of episodic prospection on farsighted decision making. *Journal of Neuroscience 31*, 6771-6779.

Bergson, H. (1911/1970). *Matter and memory*. New York, NY: Humanities Press, Inc.

Berntsen, D. & Jacobsen, A. S. (2008). Involuntary (Spontaneous) Mental Time Travel into the Past and Future. *Consciousness and Cognition, 17*, 1093–104.

Berntsen, D. & Rubin, D. C. (2004). Cultural life scripts structure recall from autobiographical memory. *Memory & Cognition, 32*, 427–442.

Berryhill, M. E., Picasso, L., Arnold, R., Drowos, D., & I.R. Olson, I. R. (2010). Similarities and differences between parietal and frontal patients in autobiographical and constructed experience tasks. *Neuropsychologia, 48*, 1385–1393

Botzung, A., Denkova, E. & Manning, L. (2008). Experiencing past and future personal events: Functional neuroimaging evidence on the neural bases of mental time travel. *Brain and Cognition, 66*, 202-212.

Buckner, R. L. (2010).The role of the hippocampus in prediction and imagination. *Annual Review of Psychology*, *61*, 27–48.

Buckner, R. L. & Carroll, D. C. (2007). Self-projection and the brain. *Trends in the Cognitive Sciences, 11*, 49-57.

Byrne, P., Becker, S. & Burgess, N. (2007). Remembering the past and imagining the future: A neural model of spatial memory and imagery. *Psychological Review 114*, 340-375.

Cabeza, R. & St. Jacques, P. (2007). Functional neuroimaging of autobiographical memory. *Trends in the Cognitive Sciences, 11*, 219-227.

Cheke, L. G. & Clayton, N. S. (2010). Mental time travel in animals. *Wiley Interdisciplinary Reviews: Cognitive Science 1*, 1-16

Cohen, N. J. & Eichenbaum, H. (1993). *Memory, amnesia and the hippocampal system*. Cambridge, MA: MIT Press

Conway, M. A., & Pleydell-Pearce, C.W. (2000). The construction of autobiographical memories in the self-memory system. *Psychological Review, 107*, 261-288.

Cooper, J. M., Vargha-Khadem, F., Gadian, D. G. & Maguire, E. A. (2011). The effect of hippocampal damage in children on recalling the past and imagining new experiences. *Neuropsychologia*, 49(7), 1843 - 1850.

Corkin, S. (2002). What's new with the amnesic patient H.M.? *Nature Reviews Neuroscience, 3*, 153-160.

Damasio, A. R. (1994). *Descartes' error: Emotion, reason, and the human brain*. New York: Putnam.

D'Argembeau, A. (2011). Motivational Aspects of Future Thinking in the Ventromedial Prefrontal Cortex, In R. Ebstein, S. Shamay-Tsoory and S. H. Chew (eds) *From DNA to Social Cognition*, John Wiley & Sons, Inc., Hoboken, NJ, USA.

D'Argembeau, A., Feyers, D., Majerus, S., Collette, F., Van der Linden, M., Maquet, P., et al. (2008). Self-reflection across time: cortical midline structures differentiate between present and past selves. *Social Cognitive and Affective Neuroscience*, *3*(3), 244-252.

D'Argembeau, A., Renaud, O., & Van der Linden, M. (2011). Frequency, characteristics, and functions of future-oriented thoughts in daily life. *Applied Cognitive Psychology, 25*, 96-103.

D'Argembeau, A., Stawarczyk, D., Majerus, S., Collette, F., Van der Linden, M., Feyers, D., et al. (2010). The Neural Basis of Personal Goal Processing When Envisioning Future Events. *Journal of Cognitive Neuroscience, 22*, 1701-1713.

D'Argembeau, A., Xue, G., Lu, Z. L., Van der Linden, M. & Bechara, A. (2008). Neural correlates of envisioning emotional events in the near and far future. *NeuroImage 40*, 398–407.

Daselaar, S. M., Rice, H. J., Greenberg, D. L., Cabeza, R. LaBar, K. S., & Rubin, D. C. (2008). The spatiotemporal dynamics of autobiographical memory: Neural correlates of recall, emotional intensity, and reliving. *Cerebral Cortex*, *18*, 217-229.

Ersner-Hershfield, H., Garton, M. T., Ballard, K., Samanez-Larkin, G. R., & Knutson, B. (2009). Don't stop thinking about tomorrow: Individual differences in future self-continuity account for saving. *Judgment and Decision Making*, *4*(4), 280-286.

Fellows, L. K. & Farah, M. J. (2005). Dissociable elements of human foresight: a role for the ventromedial frontal lobes in framing the future, but not in discounting future rewards. *Neuropsychologia, 43*, 1214–1221

Gilboa, A. & Moscovitch , M. (2002). *The cognitive neuroscience of confabulation: A review and a model*. In A.D. Baddeley , M.D. Kopelman & B.A. Wilson (Eds.), Handbook of memory disorders, (2nd ed ., pp. 315 – 342). London: John Wiley & Sons .

Gilboa, A. & Verfaellie, M. (2010). Telling It Like It Isn't: The Cognitive Neuroscience of Confabulation. *Journal of the International Neuropsychological Society 16*, 961–966.

Greenberg, D. L., Rice, H. J., Cooper, J. J., Cabeza, R., Rubin, D. C., & LaBar, K. S. (2005). Coactivation of the amygdala, hippocampus and inferior frontal gyrus during autobiographical memory retrieval. *Neuropsychologia,* 43, 659-674.

Greenberg, D. L. & Rubin, D. C. (2003). The neuropsychology of autobiographical memory. *Cortex, 39*, 687-728.

Hassabis, D. Chu, C., Rees, G., Weiskopf, N., Molyneux, P. D. & Eleanor A. Maguire, E. A. (2009). Decoding neuronal ensembles in the human hippocampus. *Current Biology 19*, 1-9.

Hassabis, D., Kumaran, D., Vann, S. D. & Maguire, E.A. (2007). Patients with hippocampal amnesia cannot imagine new experiences. *Proceedings of National Academy of Science USA*, *104*, 1726–1731.

Hassabis, D. & Maguire, E. A. (2007). Deconstructing episodic memory with construction. *TRENDS in Cognitive Sciences11*, 299-306.

Hassabis, D. & Maguire, E. A. (2009). The construction system of the brain. *Philosophical Transactions of Royal Society of London B: Biological Sciences, 364,* 1263 - 1271.

Hurley, N. C., Maguire, E. A., Vargha-Khadem, F. (2011). Patient HC with developmental amnesia can construct future scenarios. *Neuropsychologia*, 49(13), 3620 - 3628.

Ingvar, D. H. (1979). "Hyperfrontal" distribution of the cerebral grey matter flow in resting wakefulness: on the functional anatomy of the conscious state. *Acta Neurologica Scandinavica*, *60*, 12-25.

Ingvar, D. H. (1985). "Memory of the future": an essay on the temporal organization of conscious awareness. *Human Neurobiology*, *4*, 127–136.

Kirwan, C. B., Bayley, P. J., Galván, V. V. & Squire, L. R. (2008). Detailed recollection of remote autobiographical memory after damage to the medial temporal lobe. *Proceedings of National Academy of Science USA, 105,* 2676–2680.

Klein, S. B., Loftus, J. & Kihlstrom, J. F. (2002). Memory and temporal experience: The effects of episodic memory loss on an amnesic patient's ability to remember the past and imagine the future. *Social Cognition, 20,* 353–379.

Kopelman, M., Wilson, B. A., & Baddeley, A. D. (1990). *The Autobiographical Memory Interview*. Thurston, Suffolk, England: Thames Valley Test Company.

Kwan, D., Carson, N., Addis, D. R., and Rosenbaum, R. S. (2010). Deficits in past remembering extend to future imagining in a case of developmental amnesia. *Neuropsychologia 48*, 3179–3186.

Levine, B., Black, S. E., Cabeza, R., Sinden, M., McIntosh, A. R., Toth, J. P. *et al.* (1998). Episodic memory and the self in a case of isolated retrograde amnesia. *Brain 121*, 1951–1973

Levine, B., Svoboda, E, Hay, J. F., Winocur, G. & Moscovitch, M. (2002). Aging and Autobiographical Memory: Dissociating Episodic From Semantic Retrieval. *Psychology and Aging*, *17*, 677-689.

Leyhe, T., Müller, S., Eschweiler, G. W. & Saur, R. (2010). Deterioration of the memory for historic events in patients with mild cognitive impairment and early Alzheimer's disease. *Neuropsychologia, 48, 4093–4101.*

Maguire, E. A. (2001). Neuroimaging studies of autobiographical event memory. *Philosophical Transactions of Royal Society of London B: Biological Sciences*, *356,* 1441 - 1451.

Maguire, E.A., Gadian, D. G., Johnrude, I.S., Good, C. D., Ashburner, J., Frankowiak, R. S. J. & Frith, C. D. (2000). Navigation-related structural change in the hippocampi of taxi drivers. *Proceedings of National Academy of Science USA 97*, 4398-4403.

Maguire, E. A. & Hassabis, D. (2011). The construction System of the Brain. In M. Bar (eds.) *Predictions in the Brain*, (pp. 70–82), Oxford University Press.

Maguire, E. A., Vargha-Khadem, F. & Hassabis, D. (2010). Imagining fictitious and future experiences: evidence from developmental amnesia. *Neuropsychologia*, *48*, 3187 - 3192.

Moscovitch, M., Rosenbaum, R. S., Gilboa, A., Addis, D. R., Westmacott, R., Grady, C. L., et al. (2005). Functional neuroanatomy of remote episodic (autobiographical), semantic and spatial memory in humans as determined by lesion and functional neuroimaging studies: A unified account based on Multiple Trace Theory. *Journal of Anatomy, 2007*, 35-66.

Moscovitch, M., & Winocur, G. (2002). The frontal cortex and working-with memory. In D. T. Stuss & R. T. Knight (Eds.), *Principles of frontal lobe function* (pp. 189–209). Oxford: Oxford University Press.

Mullally, S. L., Hassabis, D. & Maguire, E. A. (2012). Scene construction in amnesia: an FMRI study. *The Journal of Neuroscience*, 32(16), 5646 - 5653.

Nadel, L., & Moscovitch, M. (1997). Memory consolidation, retrograde amnesia and the hippocampal complex. *Current Opinion in Neurobiology*, *7*, 217–227.

Nadel, L., Samsonovich, A., Ryan, L., & Moscovitch, M. (2000). Multiple trace theory of human memory: Computational, neuroimaging, and neuropsychological results. *Hippocampus*, *10*, 352–368.

Newby-Clark, I. R., & Ross, M. (2003). Conceiving the past and future. *Personality and Social Psychology Bulletin*, *29*, 807-818.

Okuda, J., Fujii, T., Ohtake, H., Tsukiura, T., Tanji, K., Suzuki, K., Kawashima, R., Fukuda, H., Itoh, M. & Yamadori, A. (2003). Thinking of the future and the past: The roles of the frontal pole and the medialtemporal lobes. *Neuroimage 19*, 1369–1380.

Peters, J. & Büchel, C. (2010). Episodic future thinking reduces reward delay discounting through an enhancement of pre-frontal-mediotemporal interactions. *Neuron 66*, 138-148.

Race E., Keane M.M. & Verfaellie M. (2011). Medial temporal lobe damage causes deficits in episodic memory and episodic future thinking not attributable to deficits in narrative construction. *The Journal of Neuroscience 31*, 10262–10269.

Rasmussen, K.W. & Berntsen, D. (in press). Autobiographical memory and episodic future thinking after modereate to severe traumatic brain injury. *Journal of Neuropsychology*. Doi: 10.1111/jnp.12003.

Rosenbaum, R. S., Carson, N., Abraham, N., Bowles, B., Kwan, D., Köhler et al. (2011). Impaired event memory and recollection in the case of developmental amnesia. *Neurocase 17*, 394-409.

Rosenbaum R. S., Gilboa A., Levine B., Winocur G. & Moscovitch M. (2009). Amnesia as an impairment of detail generation and binding: evidence from personal, fictional, and semantic narratives in K.C. *Neuropsychologia 47*, 2181–2187.

Rosenbaum, R. S., Köhler, S., Schacter, D. L., Moscovitch, M., Westmacott, R., Black, S. E. & Tulving, E. (2005). The case of K.C.: contributions of a memory impaired person to memory theory. *Neuropsychologia 43*, 989–1021.

Ryan, L. Lin, C. Y., Ketcham, K. & Nadel, L. (2010). The role of the medial temporal lobe in retrieving spatial and nonspatial relations from episodic and semantic memory. *Hippocampus 20*, 11-18.

Schacter, D. L. & Addis, D. R. (2007). The cognitive neuroscience of constructive memory: Remembering the past and imagining the future. *Philosophical Transactions of Royal Society of London B: Biological Sciences, 362,* 773–786.

Schacter, D.L. & Addis, D.R. (2009). On the nature of medial temporal lobe contributions to the constructive simulation of future events. *Philosophical Transactions of the Royal Society London B: Biological Sciences, 364*, 1245-1253.

Schacter, D.L., Addis, D. R. & Buckner, R. L. (2008). Episodic Simulation of future events. Concepts, Data, and Applications. *Annals of the New York Academy of Sciences, 1124*, 39-60.

Scoville, W. B., & Milner, B. (1957). Loss of recent memory after bilateral hippocampal lesions. *Journal of Neuropsychiatry and Clinical Neurosciences, 12*, 103–113.

Smallwood, J., Nind, L. & O'Connor, R.C. (2009) When is your head at? An exploration of the factors associated with the temporal focus of the wandering mind. *Consciousness & Cognition, 18*, 118-125.

Spreng, R. N., Mar, R.A., & Kim, A.S.N. (2009). The common neural basis of autobiographical memory, prospection, navigation, theory of mind and the default mode: A quantitative meta-analysis. *Journal of Cognitive Neuroscience,* 21, 489-510.

Squire, L. R., & Alvarez, P. (1995). Retrograde amnesia and memory consolidation: A neurobiological perspective. *Current Opinion in Neurobiology, 5*, 169–177. s. 10

Squire, L. R., van der Horst, A. S., McDuff, S. G. R., Frascino, J. C., Hopkinse, R. O., and Mauldin, K. N. (2010). Role of the hippocampus in remembering the past and imagining the future. *Proceedings of the national Academy of Sciences of the USA, 107*, 19044–19048.

Staresina, B. P. & Davachi, L. (2009). Mind the gap: binding experiences across space and time in the human hippocampus. *Neuron 63*. 267-276.

Steinvorth, S., Levine, B. & Corkin, S. (2005). Medial temporal lobe structures are needed to re-experience remote autobiographical memories: evidence from H.M. and W.R. *Neuropsychologia 43*, 479–496s.

Stuss, D.T. (1991). Disturbance of self-awareness after frontal system damage. In *Awareness of Deficit After Brain Injury* (Prigatano, G.P. and Schacter, D.L., eds), pp. 63–83, Oxford University Press

Suddendorf, T. (2010). Episodic memory versus episodic foresight: Similarities and differences. *Cognitive Science, 1*, 99-107.

Suddendorf, T. & Corballis, M. C. (1997). Mental time travel and the evolution of the human mind.

Genetic, Social, and General Psychology Monographs 123, 133–167.

Suddendorf, T. & Corballis, M. C. (2007). The evolution of foresight: What is mental time travel, and is it unique to humans? *Behavioural and Brain Sciences 30*, 299–351.

Svoboda, E., McKinnon, M. C., & Levine, B. (2006). The functional neuroanatomy of autobiographical memory: A meta-analysis. *Neuropsychologia*, *44*, 2189–2208.

Szpunar, K. K. (2010). Episodic future thought: An emerging concept. *Perspectives on Psychological Science*, *5*, 142-162.

Szpunar, K. K., Chan, J. C. K., & McDermott, K. B. (2009). Contextual processing in episodic future thought. *Cerebral Cortex*, *19*, 1539-1548.

Szpunar, K. K., Watson, J. M. & McDermott, K. B. (2007). Neural substrates of envisioning the future. *Proceedings of the national Academy of Sciences of the United States of America, 104*, 642-647.

Talland, G. A. (1965). *Deranged Memory: a Psychonomic Study of the Amnesic Syndrome.* New York: Academic.

Tulving, E. (1972). Episodic and semantic memory. In E. Tulving & W. Donaldson (Eds.), *Organization of memory* (pp. 381–403). New York: Academic Press.

Tulving, E. (1983). *Elements of Episodic Memory*. Oxford University Press

Tulving, E. (1985). Memory and consciousness. *Canadian Psychology, 26*, 1-12.

Tulving, E. (2002a). Episodic memory: From mind to brain. *Annual Review of Psychology*, *53*, 1–25.

Tulving, E. (2002b). Chronesthesia: Conscious Awareness of Subjective Time. In D. T. Stuss & R. T. Knight (Eds.), *Principles of Frontal Lobe Function* (pp. 311-325). Oxford: University Press.

Tulving, E. (2005). Episodic memory and autonoesis: Uniquely human? In H. S. Terrace & J.

Metcalfe (Eds.), *The missing link in cognition: Origins of self-reflective consciousness* (pp. 3–56). New York: Oxford University Press.

de Vito, S., Gamboz, N., Brandimonte, M. A., Barone, P., Amboni, M., & Della Sala, S. (2012). Future thinking in Parkinson's disease: An executive function?. *Neuropsychologia*, *50*, 1494–1501.

Wearing, D. (2005). *Forever Today*. New York, NY: Doubleday.

Weiler, J.A., Suchan, B. & Daum, I. (2010). When the future becomes the past: Differences in brain activation patterns for episodic memory and episodic future thinking. *Behavioral Brain Research, 212:196-203*.

Weiler, J. A., Suchan, B., Koch, B., Schwarz, M. & Daum, I. (2011). Differential Impairments of Remembering the Past and Imagining Novel Events after Thalamic Lesions. *Journal of Cognitive Neuroscience 23.* 3037-3051.

Wheeler, M.A., Stuss, D.T. & Tulving, E. (1997). Toward a theory of episodic memory: the frontal lobes and autonoetic consciousness. *Psychological Bulletin*, *121*, 331-354.

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Table 1: Summary of memory and future thinking in reported patient studies.

Study	Patient(s)	Onset/ etiology	Neurological damage	Semantic Memory			Episodic Memory		
				Access to general semantics	Access to personal semantics	Ability for semantic future thinking	Access to Episodic Details	Ability to construct future events	Ability to construct fictional events
Scoville & Milner (1957), Corkin (2002)	H.M.	Adult/ resection to relief epilepsy	Large MTL lesion bilateral including the medial temporal polar cortex, amygdala, entorhinal cortex and hippocampal formation	**Yes** - intact general semantics	**Yes** – but some deficits for recent personal semantics	Not reported	**Some** - temporally graded amnesia, could recall some childhood memories, but had difficulty remembering events that happened during the years preceding the surgery	**No** – unable to make predictions about his personal future	Not reported
Tulving (1985), Rosenbaum et al. (2005, 2009),	K.C. (N.N.)	Adult/ traumatic brain injury	MTL including hippocampus bilateral, para-hippocampus and diencephalon, occipitotemporal and fronto-parietal cortex	**Yes** – intact general semantics	**Yes** – but some deficits for recent personal semantics (AMI-PS)	**Some** – can provide schematic or script-like information of going to a restaurant or making a long-distance phone call	**No** – dense retrograde amnesia, cannot remember a single episode from the past (AMI-AI, AI-PI)	**No**- describes his mind as "blank" when asked about future events	**No** – impaired ability to generate fictional events
Stuss (1991)	R.	Adult/ astro-cytoma that was surgically removed	Right prefrontal cortex	**Yes** - intact general semantics	**Yes** – intact knowledge of own life and deficits	**Yes** – intact knowledge of the future. Can analyze facts about her own situation and make reasonable recommendations about her daily life	Not reported	**Some** – impaired self-awareness regarding the use of intact knowledge to guide personal decisions about her future	Not reported

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Table 1: ***continued***

Study	**Patient(s)**	**Onset/ etiology**	**Neurological damage**	**Semantic Memory**			**Episodic Memory**		
				Access to General Semantics	**Access to Personal Semantics**	**Ability for Semantic future thinking**	**Access to Episodic Details**	**Ability to construct future events**	**Ability to construct fictional events**
Levine et al. (1998)	M.L.	Adult/ traumatic brain injury	Right ventral frontal cortex/ uncinate fasciculus	**Yes** - intact general semantics	**Yes** – can learn significant facts from his own past	**Some** - can use structured routines to aid in resuming former responsibilities such as parenting	**No** - inability to re-experience events pre-dating his injury, newly formed memories lack autonoetic qualities	**Some** – impaired on a strategy application task, his behavior demonstrates lack of awareness of the future	Not reported
Klein, Loftus and Kihlstrom (2002)	D.B.	Adult/ anoxia following cardiac arrest	Unknown	**Yes**- intact memory for past issues/ events in public domain (KPF)	Not reported	**Yes** - can answer questions about future issues in the public domain likely to take place (KPF)	**No** –dense retrograde amnesia for past events from any point in his life (LPF)	**No** – cannot imagine personal future events (LPF)	Not reported
Hassabis et al. (2007); Mullally, Hassabis, and Maguire (2012)	5 amnesic patients	Adult/menigoencephalitis(P01)/ limbic encephalitis (P02, P03, P04, P05)	All patients had damage to the hippocampus bilateral Additional areas affected: P01 bilateral abnormalities in occipital lobe P02 generalized atrophy P03 and P04 amygdala bilateral	**Yes** – all patients had intact general semantics	P01 **Yes** – intact P02 **Yes** – but some deficits for recent personal semantics P03 **Yes** – but deficits for childhood personal semantics P04 and P05 Not reported	Not reported	P01 and P02 **No** – dense retrograde amnesia P03 **Some** – retrograde amnesia for events in childhood and early adulthood P04 and P05 **Some** – retrograde amnesia for events extending back 10 and 20 years respectively	Not reported	P01 **Yes** – can imagine fictional scenes with richness and coherence comparable to controls (SC) P02, P03, P04 and P05 **Some** – can imagine fictional scenes significantly reduced in richness and coherence compared to controls (SC)

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Study	**Patient(s)**	**Onset/ etiology**	**Neurological damage**	**Semantic Memory**			**Episodic Memory**		
				Access to General Semantics	**Access to Personal Semantics**	**Ability for Semantic future thinking**	**Access to Episodic Details**	**Ability to construct future events**	**Ability to construct fictional events**
Andelman et al. (2010)	M.C.	Adult/ anoxia after epileptic seizure	Hippocampus bilateral	**Yes** – intact general semantics	**Yes** – impaired personal semantics extending 3 years back	**Yes** - can answer questions about future issues in the public domain likely to take place (KPF)	**Yes** - retrograde amnesia for past events extending 3 years back	**No** - only vague responses for personal future (LPF)	Not reported
Maguire et al. (2010)	Jon	Birth/ perinatal hypoxic ischemia	Hippocampus bilateral	**Yes** – intact general semantics	Not reported	Not reported	**Some** - amnesia for past experiences, however preserved memory for a small number of events	**Yes** - can imagine possible future scenes with richness and coherence comparable to controls (SC)	**Yes** - can imagine fictional scenes with richness and coherence comparable to controls (SC)
Kwan et al. (2010), Rosenbaum et al. (2011), Hurley et al. (2011)	H.C.	Birth/ perinatal hypoxic ischemia	Hippocampus bilateral, the thalamus and basal ganglia bilaterally, and right retrosple-nial cortex	**Yes** – intact general semantics	**Yes** – intact personal semantics, number of semantic details were within normal range (AI-PE)	**Yes** - number of semantic details were within normal range (AI-FE)	**Some** – amnesia for past events, can recall some events, but with significant reduction of episodic details (AI-PI)	**Some** - significant reduction of episodic details in future events (AI-FI, but see Hurley et al., 2011); can imagine future scenes (SC).	**Yes** - can imagine fictional scenes (SC)

Table 1: ***continued***

Study	Patient(s)	Onset/ etiology	Neurological damage		Semantic Memory			Episodic Memory	
				Access to General Semantics	Access to Personal Semantics	Ability for Semantic future thinking	Access to Episodic Details	Ability to construct future events	Ability to construct fictional events
Squire et al. (2010); Bayley et al. (2006)	6 patients with bilateral hippo-campal damage	Adult/anoxia (G.W., R.S.)/ ischemia (J.R.W., K.E.)/viral encephalitis (G.P)/ unknown (L.J.)	5 of the patients had damage re-stricted to the hippocampus bilateral Patient GP, damage bilateral to the hippocampus, amygdala, parahippocam pal and fusiform gyri, temporal cortex and left insula	**Yes** – intact general semantics Patient GP **Some** – deficits acquiring new semantic knowledge, and deficits in general semantics covering 20 years prior to the onset of amnesia	**Yes** – Intact personal semantic (AMI-PS and AI-PE) Patient GP **Some** - intact personal semantic for more remote time periods (AMI-PS), provided fewer semantic details (AI-PE)	Not reported	**Yes** - intact remote autobio-graphical memory and modestly impaired recent memory (AI-PI) Patient GP **Some** - Intact remote autobiographical memory, but severely impaired recent memory (AI-PI).	**Yes** – can imagine future events with same amount of details as controls (AI-FI) Patient GP **Some** – can imagine future events, but reduction in sensory details (AI-FI)	Not reported
Berryhill et al. (2010)	2 patients with bilateral posterior parietal lesions	Adult/ infarcts (P01)/ cerebral vasculitis (P02)	Bilateral inferior parietal lesions	**Yes** – intact general semantics	**Some –** provide fewer semantic details when having to describe autobiographical memories (AI-PE)	Not reported	**Some** – provide fewer episodic details when having to describe autobiographical memories (AI-PI)	Not reported	**Some** – can imagine fictional scenes signify-cantly reduced in richness and coherence compared to controls (SC)

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Table 1: ***continued***

Study	**Patient(s)**	**Onset/ etiology**	**Neurological damage**	**Semantic Memory**			**Episodic Memory**		
				Access to General Semantics	**Access to Personal Semantics**	**Ability for Semantic future thinking**	**Access to Episodic Details**	**Ability to construct future events**	**Ability to construct fictional events**
Berryhill et al. (2010)	5 patients with unilateral prefrontal damage	Adult/ astrocytoma (P01)/ infarct (P02, P04 and P05)/ hemorrhage (P03)	P01 left superior frontal gyrus P02 left internal capsule and inferior frontal gyrus P03 superior middle frontal cortex P04 fronto-tempo-ral cortex and basal ganglia. P05 orbitofrontal cortex and inferior frontal gyrus	**Yes** – intact general semantics	**Yes** – intact personal semantics, number of semantic details were within normal range (AI-PE)	Not reported	**Yes** – intact autobiographical memory, number of episodic details were within normal range (AI-PI)	Not reported	**Some** – can imagine fictional scenes significantly reduced in richness and coherence compared to controls (SC)
Weiler et al. (2011)	2 patients with thalamic lesions	Adult/ infarct of the para-median artery	P01 Bilateral lesions in the medial dorsal nucleus of the thalamus P02 Right-sided lesion in the medial dorsal nucleus of the thalamus	P01 **No** – gave sig-nificantly fewer facts about public past events (KPF) P02 **Yes**- intact me-mory for past issues/ events in the public domain (KPF)	**Yes** – intact personal semantics (AMI-PS)	P01 **No** – gave fewer facts about future issues in the public domain likely to take place (KPF) P02 **Yes**- can answer questions about future issues in the public domain likely to take place (KPF)	**Yes** – intact ability to generate past events (SC)	**Some** – milder deficits in the ability to imagine future events (SC)	**Some** - impaired ability to generate fictional and impersonal events (SC)

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Table 1: ***continued***

Study	Patient(s)	Onset/ etiology	Neurological damage	Semantic Memory			Episodic Memory		
				Access to General Semantics	**Access to Personal Semantics**	**Ability for Semantic future thinking**	**Access to Episodic Details**	**Ability to construct future events**	**Ability to construct fictional events**
Race et al. (2011)	8 amnesic patients	Adult/limbic encephalitis (P01, P02, P06) /anoxia (P03, P04, P05, P07 and P08)	P01 hippocampus bilateral P02 hippocampus, bilateral, right lateral tempo-ral cortex P04 Hippocampus bilateral, left lateral tempo-ral cortex P05 Right hippocampus P03, P06,P07 and P08 Unknown	**Yes** – intact on combined measure of general semantics (WAIS – VIQ)	**Yes** – intact personal semantics, number of semantic details were within normal range (AI-PE)(only mean performance is reported)	**Yes** - number of semantic details were within normal range (AI-FE))(only mean performance is reported)	**Some** – amnesia for remote and recent past events, can recall some events, but with reduced episodic detail compared to controls (AI-PI)(only mean performance is reported)	**Some** – can imagine some future events, but with reduced episodic detail compared to controls (AI-FI) (only mean performance is reported)	Not reported
Cooper et al. (2011)	21 children with develop-mental amnesia	Infancy/neo natal hypoxia/isch aemia	Hippocampus bilateral	**Yes** – intact on combined measure of general semantics (WAIS – VIQ)	Not reported	Not reported	**Some** – impaired in recalling specific details of episodes, cannot remember events from testing session from previous day	Not reported	**Yes** – can imagine fictional scenes with richness and coherence comparable to controls (SC)

Notes: The Table represents an extension of previous overviews by Atance and O'Neill (2001) and Addis and Schacter (2012). Measures used to assess autobiographical memory and future thinking noted when reported. AMI-PS, Autobiographical Memory Interview – personal semantics (Kopelman et al., 1990); AMI-AI, Autobiographical Memory Interview – autobiographical incidents (Kopelman et al., 1990); AI-PI, Autobiographical Interview – past internal detail score (Levine et al., 2002); AI-PE, Autobiographical Interview – past external detail score (Levine et al., 2002) AI-FI: Autobiographical Interview – Future Internal detail score (Addis et al., 2008); AI-FE: Autobiographical Interview - Future External detail score (Addis et al., 2008); LPF: Lived Past-Future (Klein et al., 2002); KPF: Known Past-Future (Klein et al., 2002); SC: Scene Construction Task (Hassabis et al., 2007). Abbreviations: Pxx, patient number for identification of single cases.