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Remembering the past and thinking about the future: Is it really about time?

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ABSTRACT

In this paper we discuss some literature relating to episodic memory, future episodic thinking and mental time travel in humans and non-human animals. We discuss the concept of mental time travel and argue that the concept relies on subjective phenomena such as consciousness and on this basis is not useful when studying episodic memory and future episodic thinking, particularly in non-human animals. We discuss recent work which emphasizes views of both episodic memory and future thinking which do not rely on such mental time travel and, more importantly, give less prominence to the concept of time. The implications of such a view for research into future thinking in non-human animals are considered.

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Humans are capable of remembering personally experienced events from the past, an ability termed episodic memory (Tulving, 1983). This ability to reminisce about past events is increasingly being understood as having evolved to aid future decision making: remembering past events, actions and outcomes might be crucial to subsequent planning of future actions (e.g. Buckner & Carroll, 2007; Suddendorf & Corballis, 1997). In one sense all memory is future orientated as events in the past have the potential to affect future behavior (Quinn & Rosenthal, 2012), even in tasks such as conditioning. However, unlike a learned association between two elements such as a light and food or simply having a memory for information about your life, such as when and where you were born, remembering events that you have experienced in your life is associated with a conscious experience akin to reliving the event itself. This ability to mentally re-experience a past event through autonoetic consciousness (Tulving, 1983) has led to the concept of mental time travel (MTT).

Mental time travel is envisaged as the ability to mentally re-experience events from the past but also to mentally imagine possible future events (Suddendorf & Busby, 2003; Suddendorf & Corballis, 1997). When such mental time travel is directed toward the past it is termed episodic memory (Tulving, 1983). Such thinking about possible future events has variously been called future planning (e.g. Clayton, Bussey, & Dickinson, 2003), future thinking (e.g. Atance & O'Neill, 2001) or episodic future thinking (e.g. Russell, Alexis, & Clayton, 2010) but all share the essential characteristics of thinking about a hypothetical future event that involves the self and which can be used flexibly to plan future actions. Thus one can, for example, remember a past dinner party and mentally re-experience the good humored discussion around the table. But one can also imagine a future dinner party, consider the effects of the strong opposing views of some of the potential guests and plan invitations accordingly. Such planning, it has been argued, depends on mentally experiencing the possible future scenario. Thus both MTT into the past and into the future share some characteristics. Both, it has been argued, require conscious (re-)experience or autonoetic consciousness. As a result, it has been claimed that both are a uniquely human ability (Suddendorf & Corballis, 1997). Similarly, both involve a projection of the self into the past or future (Atance & O'Neill, 2001) and again, this link to a sense of self has equally severely limited the application of the concept of MTT to non-human animals. Within humans, the characteristics of MTT into the past and future also appear to have some similarities. For example, individual differences (for

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example, in time perspective (Arnold, McDermott, & Szpunar, 2011) or creativity (D'Argembeau & Van der Linden, 2006)) affect memory for past events and imagining of future events in equivalent ways. Similarly, the amount of sensory and contextual detail within the reported experiences of both past and future events was greater for events that were closer to the present than for those which were more distant and, possibly as a result, were associated with stronger feelings of re- or pre-living (D'Argembeau & Van der Linden, 2004). Thus in the same way it is easier for most of us to recall details of a recent dinner party than a more distant one, it is also possible to imagine in more detail a forthcoming dinner party than one in the more distant future. This increasing blurring of the future with increasing distance from the present may in part explain the "distant elephant" phenomenon well known to academics by which it is easy to accept a commitment for the far future (next term, next year) confident that, viewed from sufficient distance, the commitment is easily manageable: it is only when the time nears that the full size of the task becomes apparent.

The problem with mental time travel

The linking of episodic memory and future thinking under the umbrella term of 'mental time travel', however, raises a problem that the conceptual relationship between them is one based almost entirely on conscious **experience**. In each case the experience of the individual is a conscious creation of an event that has either occurred in the past or which may happen in the future, and is subject to autonoetic consciousness (Tulving, 1983). However, such links to subjective experiential similarities are not helpful in defining cognitive processes. For example, the experience of seeing a color within an object (e.g. that a disc is red) and detecting the colored border of an object (e.g. the edge of a red disc against an isoluminent blue background) appear subjectively very similar if not indistinguishable, but rely on fundamentally different cognitive processes and different brain regions (Heywood, Cowey, & Newcombe, 1991). Therefore a reliance on entirely subjective phenomena in linking cognitive processes is not robust.

In addition, as discussed above, any definition of behavior or cognition in terms of conscious experience immediately limits the demonstration of such abilities to situations where conscious experience can be examined. As a result the difficult issue of the existence of conscious experience in nonhuman animals and how one might demonstrate such consciousness becomes crucial to the consideration of MTT in animals. Based on a definition of MTT which includes the requirement of conscious experience, one can imagine a hypothetical world in which an animal undoubtedly did have the ability for MTT (but not language) and ask whether it would be possible to demonstrate the ability to the satisfaction of a cynic. While suggestions as to how this might be achieved have been made (Suddendorf & Busby, 2003), it remains a difficult and controversial issue (Clayton, Bussey, Emery, & Dickinson, 2003). This suggests that it may be more useful to consider a definition of MTT that does not require a demonstration of conscious (re-)experience, although remaining neutral on the question of whether consciousness itself may or may not be an integral part of such an ability. Such a definition would not a priori rule out any demonstration of MTT in non-human animals, although it would nonetheless allow for the possibility that non-human animals may not have such an ability. However, it may be that elements of consciousness and self-projection are integral to the concept of MTT and without these elements it becomes an empty shell. For example, within a section entitled "Toward a definition of mental time travel", Suddendorf and Corballis (2007) write "We know what mental time travel is because we can introspectively observe ourselves doing it and because people spend so much time talking about their recollections and anticipations" (p. 301). Thus without introspection, language and consciousness, the definition of MTT as an experimentally useful concept diminishes. Yet without MTT, a crucial conceptual link between episodic memory and future thinking is broken. This suggests that alternative descriptions of both episodic memory and future thinking are required that allow both to be demonstrated without appeal to unobservable phenomena such as consciousness or introspection. In addition, the nature of the connection between the two, if not based on a shared requirement for MTT, must be clarified.

There are such consciousness-neutral definitions of episodic memory which are based on the content and structure of the memory. Clayton and colleagues, for example, based such a definition on Tulving's (1983) original definition of episodic memory as memory that 'receives and stores information about temporally dated episodes or events, and temporo-spatial relations between them' and, in recognition that it lacked the later requirement of autonoetic consciousness (Tulving, 2002), termed it episodic-like memory (Clayton & Dickinson, 1998). Thus Clayton and colleagues claim that an integrated representation of what happened, where and when that can be flexibly expressed fulfills the definition of an episodic-like memory. In subsequent work, we have argued (e.g. Eacott & Easton, 2010; Eacott & Norman, 2004; Easton & Eacott, 2008) that the temporal element (when) of the what–where–when triad may be too narrow a term and should be extended to incorporate any aspect of the event which allows a particular past occasion to be identified (i.e. replacing when something happened with the concept of which occasion it happened on). While an occasion may be identified by temporal cues (e.g. at noon, 3 days ago, or last December), it could equally use non-temporal identifiers as long as they allow a specific occasion to be pinpointed (e.g. while I was eating lunch, at the staff meeting, at the departmental Christmas party). Such definitions allow the question of episodic-like memory in non-human animals to be addressed without any requirement for demonstration of conscious experience. Through a series of studies, it is now well established that scrub jays can demonstrate good memory which meets this criterion. For example, they show memory for what items they cached, in what location within a caching tray and how long ago the caching event took place (Clayton & Dickinson, 1998). This memory is in an integrated form and can be flexibly expressed over relatively long periods of time (e.g. Clayton & Dickinson, 1998; Clayton, Griffiths, Emory, & Dickinson, 2001). Equally, rats have been shown to have an integrated and flexibly used memory for objects seen in particular locations (what and where) on identifiable past occasions (when or which occasion), where these past occasions are cued by the visuo-spatial context present (Eacott, Easton, & Zinkivskay, 2005; Eacott & Norman, 2004). Again, this task demonstrates memory which meets this consciousness-neutral definition of episodic(-like) memory.

However, such definitions have not been directly translated into a comparable definition of future thinking for use with non-human animals. Discussion of future thinking abilities in non-human animals tends to rely on the Bischof-Köhler hypothesis (Suddendorf & Corballis, 1997, 2007) which suggests that any demonstration of such thinking should be independent of the animal's current motivation state. For example, an animal which chooses a tool (over similar but non-functional objects) which it will use later to gain tasty food may appear to be engaging in future thinking (Mulcahy & Call, 2006). However, if the animal at the point of choosing the tool is motivated to obtain the food, the choice may be firmly embedded in the present, even though expression of the act may not take place until a future point in time (see Roberts, 2012, for further discussion of task). Therefore, in order to unambiguously demonstrate future thinking the behavior of the animal must be related not to its current motivational state, but to some foreseeable future state. For example, Raby, Alexis, Dickinson, and Clayton (2007) gave scrub jays experience of two overnight sleeping chambers. In one they had dog kibble available for breakfast in the morning while in the other they had peanuts. After experiencing this contingency, they were unexpectedly given both dog kibble and peanuts in the evening which they could cache in the two sleeping chambers. The scrub jays preferentially cached the food that would not otherwise be available in each sleeping chamber (i.e. dog kibble in the chamber which supplied only peanuts for breakfast and peanuts in the chamber which typically supplied only dog kibble). Crucially, they did not simply cache one food (e.g. dog kibble) because they had a current preference for that food, nor cache both in each chamber if they had no food preference. By selectively and differentially caching both foods according to an anticipated future situation or need in each sleeping chamber, it is claimed that they demonstrated future thinking. Yet, there is a possibility that the selective caching even here may be based on a current motivational state generated by associations between the sleeping chamber and the associated foodstuff rather than an anticipated future motivational state as the motivational state of the birds was not specifically manipulated (see Roberts, 2012, for further discussion of this task). Therefore in a related experiment, Clayton and colleagues (Correia, Dickinson, & Clayton, 2007) specifically manipulated the motivational state of the scrub jays by pre-feeding them with specific food-types. Typically, scrub jays (like other animals) will maximize the variety in the diet by preferentially eating and/or caching a different over the same foodstuff when pre-fed a particular type of food (Rolls, Rolls, Rowe, & Sweeney, 1981). Thus by prefeeding specific food-types, Clayton and colleagues could manipulate the motivational state of the scrub jay toward a particular food and moreover this could be dissociated between the state at caching and at retrieval of caches. Thus one group of jays was pre-fed different food-types before caching and retrieval of those caches. Therefore their motivation to eat a particular food-type differed between caching and retrieval. Nonetheless, the food-type cached did not depend on the motivational state at caching (which would favor caching of the food-type different to that pre-fed before caching but the same as the food-type to be pre-fed before retrieval). Instead, jays preferentially cached food-types which matched that which they had recently been pre-fed and so for which they had little current desire. However, this behavior resulted in the availability of a food-type at retrieval which they were highly motivated to retrieve. Thus, by manipulating motivation toward eating two foodstuffs at caching and retrieval, Clayton and colleagues revealed that caching behavior was controlled not by the motivational state at the time of caching, but on an anticipated state at the time of retrieval, (i.e. they anticipated a future need). As a result, this demonstration most directly addresses the Bischof-Köhler hypothesis, in showing future orientated behavior that is specifically dissociated from the current motivational state in a non-human animal (see also Beran, Perdue, Bramlett, Menzel, & Evans, 2012; Crystal, 2012, for a different approach to this issue). Crucially, this demonstration does not necessarily involve any consideration of conscious awareness.

What do episodic memory and future thinking really have in common?

Thus there are useful definitions of both episodic(-like) memory and future thinking which exclude conscious experience and can therefore be used to test for the existence of these abilities in non-human animals. While these descriptions are more useful in that they allow a less subjective description of the cognitive process, if the concept of MTT is lost then the primary element of similarity between the two is also lost. What, if anything, therefore do these two abilities share in common? Both involve representations of events which differ from the currently experienced reality and which can be flexibly expressed. However, episodic memory does not necessarily require different motivational states to be present at the time of the re-experience from the time of the initial event; indeed memory for a past event may be triggered by the current state, while this is a key component of demonstrating future thinking. If these two processes are truly linked, then there should be evidence beyond a shared conscious experience to show they have underlying mechanisms in common. Recently it has been argued that there is a fundamental link in the underlying brain mechanisms, a core brain network, which supports both episodic memory and future episodic thinking (Buckner & Carroll, 2007).

One line of evidence for this view comes from neuropsychological patients. Patients with lesions including the hippocampus are well known to have severe impairments in episodic memory (e.g. Scoville & Milner, 1957; Zola-Morgan, Squire, & Amaral, 1986). However, recently attention has focused on these same patients' imaginings of hypothetical future experiences. The evidence clearly shows that patients with impaired episodic memory are also impaired at imagining possible future events. For example, a severely amnesic patient, DB, had great difficulty imagining what his personal future might hold (Klein, Loftus, & Kihlstrom, 2002). DB's amnesia followed an anoxic episode subsequent to a heart attack and it is likely he suffered widespread brain damage. However, amnesic patients that have damage localized to the hippocampus also typically have difficulty imagining any hypothetical event whether it is placed in the future or not (Hassabis, Kumaran, Vann, & Maguire, 2007; but see Maguire & Hassabis, 2011; Squire et al., 2011). Therefore there is good evidence that the hippocampus is necessary both for the remembering of events in the past and the imagining of events in the future. This may suggest that the two rely on at least one shared hippocampally dependent process.

Indeed, groups without explicit hippocampal damage but with impaired episodic memory also show impaired future thinking, again suggesting the two share crucial cognitive processes. For example, high functioning individuals with autism spectrum disorder (ASD) both recalled significantly fewer specific events than comparison participants, demonstrating impaired episodic memory, but also imagined fewer future events (Lind & Bowler, 2010; Lind & Williams, 2012). Equally, in depressed participants both memories for past events and imaginings of future events were over-generic and the amount of detail in each was correlated, again suggesting a similar underlying process (Williams et al., 1996).

However, one group of patients may provide contrasting evidence. Those with amnesia resulting from hippocampal damage at a young age (in contrast with adult-onset cases above) may not typically be impaired at future thinking despite having damage to the hippocampus and severely impaired episodic memory (Cooper, Vargha-Khadem, Gadian, & Maguire, 2011; Maguire, Vargha-Khadem, & Hassabis, 2010). For example, Jon, an adult with well studied developmental amnesia resulting from birth difficulties, was able to imagine future or fictitious events despite his severe amnesia for past events (Maguire et al., 2010). This finding raises the possibility that while impairments in episodic memory and future thinking may often co-occur, there is no necessary association between the two and that there may be dissociations. Such evidence would fundamentally undermine the view that episodic memory and future thinking are essentially based on the same underlying abilities to mentally time travel. While this remains possible, nonetheless it remains evidence of only a single dissociation and is therefore vulnerable to resource strength arguments. For example, it is possible that spared hippocampal tissue, which in Jon for example is as much as 50%, may be sufficient to support future thinking but not episodic memory. In support of this view, one adult onset case with hippocampal damage also had significant sparing of hippocampal tissue and showed a similar pattern of impaired episodic memory with unimpaired imagining of new events (Hassabis et al., 2007). This account suggests that imagining fictitious events demands more resources than constructing a past event on the basis of stored memory. Alternatively, it is possible that an apparent ability to engage in future thinking can be a learned strategy based on intact semantic knowledge. Indeed, the developmentally amnesic patient Jon, who succeeds on a task of future imagining, reports that it is something which is effortful for him and which he has practiced over a number of years (Maguire et al., 2010). Therefore although such patients may succeed on the future imagination task, it is important to be mindful that success on a task may not in all cases be tapping identical processes and that learned strategies must always be considered.

For this reason, it is useful to consider studies on individuals without brain damage as there is little opportunity to engage in such learned strategies. In this way the normal brain structure linked to the typical cognitive processes engaged by the tasks of remembering past experiences and imagining future events can be examined. As might be expected based on the patient data, in general these tasks have also implicated a common neural substrate in episodic remembering and episodic future thinking which includes the hippocampus. For example, Addis, Wong, and Schacter (2007) found that both remembering and future thinking engaged regions associated with episodic memory such as the left hippocampus, the parahippocampal gyrus and retrosplenial regions. However there were other areas, for example the right hippocampus, which were uniquely engaged by future thinking. Similarly a recent report (Hassabis & Maguire, 2007) suggested that remembering recent episodic memories and constructing future possible events also engaged similar regions.

Therefore the majority of the evidence from neuropsychological patients, those with developmental disorders such as ASD, typically developing adult participants and severely depressed individuals, supports the view that there is an underlying similarity between episodic memory and future imagining in that both are reliant on a brain network which includes the hippocampus. However, if one link between episodic memory and future thinking is that both are reliant on the hippocampus, then we need to more fully understand what the role of the hippocampus is in both types of cognition.

The hippocampus, episodic memory and mental time travel

The link between episodic memory and the hippocampus has been long-hypothesized (e.g. Scoville & Milner, 1957) and there is an extensive literature on the specificity of the hippocampal pathology and the underlying disrupted processing in both humans and non-humans which will not be further considered here (e.g. Aggleton & Brown, 1999; Squire, 2004). However, one thing that has become apparent in recent years is that an explicit temporal dimension is not critical for the hippocampus to be involved. Episodic tasks used with human amnesic patients do not always specifically probe the temporal element. For example, recollection of paired associates, or pictures presented to the patient can be considered episodic in nature because of the nature of the recollection (Tulving, 1983), rather than because there is any particular reference to the time frame in the patient's responses.

In work with non-human animals the criterion for demonstrating episodic(-like) memory is usually set higher and temporal aspects are increasingly considered. However, it has become apparent that an explicit temporal aspect is not always crucial. For example, Eacott and colleagues definition of episodic(-like) memory in non-human animals (what, where, which-occasion) does not specifically reference temporal cues, yet is strikingly impaired by lesions within the hippocampal system (Eacott & Norman, 2004; Easton, Zinkivskay, & Eacott, 2009; Langston & Wood, 2010). Moreover, some temporal cues, such as those relating to how long ago an event occurred rather than at what particular time point, are vulnerable to a non-hippocampal solution (Roberts et al., 2008). For example, it has recently been reported that transgenic mice with hippocampal pathology were impaired at a what–where–which episodic-like memory task but were unimpaired on a what–where–how long ago "episodic-like" memory task (Eacott, Davis, Easton, & Gigg, 2011). Those tasks which use time since the event as a relevant cue can be solved on the basis on the relative strength of memory, with memories for events that were longer ago being weaker, although there is good evidence that they may not always be solved in this way (Feeney, Roberts, & Sherry, 2011; Zhou & Crystal, 2009). Nonetheless, where an alternative strategy exists for solving what–where–how long ago tasks, a participant or non-human animal can appear to have information about when an event took place on the basis of a memory which in fact has no temporal content, only information about the strength of the non-temporal trace (Roberts et al., 2008; but see Zhou & Crystal, 2009). Such a memory does not meet the criteria for episodic memory and recent evidence suggests that it is not experienced as such (Easton, Webster, & Eacott, 2012). For example in a recent study from our laboratory designed to mimic the what–where–when and what–where–which tasks given to rats, human participants were sequentially presented with two complex scenes, each containing the same abstract objects but in different locations within the scene and each scene having a distinctive background. Participants were asked to make two-choice judgments about what they had seen, where and either when (1st or 2nd scene) or on which occasion (based on the distinctive background, stripy or checkered). In addition, participants were asked for each judgment made whether their memory for what they had seen came with a feeling of remembering (associated with episodic memory) or a feeling of knowing (associated with familiarity in the absence of episodic memory). On this task, as there were only two scenes each presented only once, asking whether an object appeared in this location on the first or second scene, or whether it was on the stripy or checkered background, both require accessing information about the location of an object on a particular occasion. The relevant occasion could be cued either by reference to relatively how long ago the occasion occurred (1st or 2nd) or to the background (stripy or checkered). It was found that participants were able to correctly make the former judgments (1st vs 2nd) even when they were not using episodic memory, as evidenced by their reports of the subjective feeling of knowing, rather than remembering. In contrast, judgments which asked participants on which occasion (stripy or checked background) they had seen objects in particular locations (what–where–which occasion) were reliant on episodic memory as they could not be reliably answered when the participant did not have an experience of remembering which is associated with episodic memory (Easton et al., 2012). Therefore, we have argued (e.g. Eacott & Easton, 2010; Easton & Eacott, 2008) that episodic memory is specifically about discriminating complex events from one another based on the arrangements of items on a particular occasion. The occasion may be defined by a number of cues, but crucially they do not have to be temporal in nature.

This conclusion that memory for a past event need not contain specifically chronological information is in agreement with much of the evidence of the role of temporal information in making judgments about the time of occurrence of episodic events. Such judgments are notoriously poor and rarely have specific information about the exact time of occurrence, whether in laboratory based tasks or in real life (Friedman, 1993). In this extensive and influential review of the literature, Friedman (1993) concluded that judgments made about when an event occurred could be actively deduced from a wide range of cues, including the apparent distance of the event from the present (e.g. trace strength or contextual overlap with the present), cues which suggested the relative order of events in time (e.g. associative chaining) as well as associated contextual information (e.g. semantic knowledge about elements of the content). However, Friedman concluded that "there is no single, natural temporal code in human memory" (p. 44) and therefore a linear chronology, such as one that an individual might travel backwards and forwards upon in MTT (e.g. Miles, Nind, & Macrae, 2010), is an illusion. Indeed, counter to the predictions of this linear model of the experienced past, the subjective experience of recollecting a past experience (episodic memory) in humans is not necessarily associated with a high rating for the feeling of traveling back in time (i.e. MTT). For example, Crawley and Eacott (2006) asked adult participants to rate the qualities of their recollections about early life experiences. Despite the fact that the participants were recalling matched event-types and were equally confident that the recollections were truly recalled rather than known from other sources, compared with those who were recalling later events (from between the ages of 28 months to 5.5 years) those who were recalling very early life events (from before the age of 28 months) gave significantly lower ratings for the feeling that they were traveling back in time or that they were reliving the events. Thus a strong feeling of MTT to relive previous experiences is not necessary to memories which are nonetheless experienced as recollections or episodic memory in humans.

What are the implications for future imaging?

What is the relationship between episodic memory and future imagining such that they rely on the same cognitive and brain processes? One simple view is that future imagining has its basis in sampling existing episodic memories. Thus when asked to imagine a scene in a beach or in a forest, one starts by retrieving memories of similar past events (Szpunar, Chan, & McDermott, 2009; Szpunar & McDermott, 2008). In support of such a view, normal participants gave much more detail in imagining future events which took place in highly familiar or recently experienced environments (e.g. their home or their university campus) over less familiar or familiar but less recently experienced environments (e.g. Great Wall of China or their high school). Thus the more detailed future imaginings were associated with contexts about which the participants had more detailed memory representations (Arnold et al., 2011) suggesting that these imagined futures may be based on the existing memories.

However, it is clear that imagining future scenarios cannot be based entirely on rearranged elements of pre-existing episodic memories as Szpunar and McDermott's (2008) participants were able to imagine events in places of which they had no direct personal experience (e.g. a jungle), although they would of course have had knowledge of the nature of these environments. A development of this view, therefore, is that imagining future events relies upon constructing a scene composed of disparate elements from a number of sources which may involve both past personal experiences (episodic memory) but also semantic memory (Hassabis & Maguire, 2007; Schacter & Addis, 2007). Crucially, such a view removes the necessity to consider the temporal component, or MTT, in future thinking. The non-centrality of a sense of MTT is indicated in Hassabis et al.'s (2007) report of the future episodic thinking of patients with hippocampal damage. The patients were, as reported above, markedly impaired in imagining possible future personal events, the imagined scenarios containing fewer entities (e.g. people, objects), sensory descriptions and spatial references. Nonetheless, the patients and the controls did not differ in their "perceived sense of presence", a self rating scale of the extent to which the participants felt that they were "really there". Although the terms differ, a perceived sense of presence would seem to demand MTT, as it involves a subjective sense of the self being present at an alternative time. Yet perceived sense of presence and the ability to envisage detailed future scenarios are dissociated, suggesting that MTT is not itself central to such future episodic thinking. Indeed Hassabis and Maguire (2009, p. 1263) have stated "We believe that time does not merit elevation to the level of an independent process with a distinct neural signature. Instead, we view the timestamp of an event (whether future or past) as simply the result of a content or goal difference rather than a change in the fundamental processes involved."

Thus under this view, both future imagining and episodic memory can be viewed as similar in involving the construction of a scene (Hassabis & Maguire, 2007; Schacter & Addis, 2007), involving objects in spatial locations within a background scene and the temporal context (i.e. whether it is now, past or future) is only an additional constraint. The constraint might be that the imagining is anchored in the future (e.g. what will you be doing in five years time?) which must be constrained by present achievements and natural processes such as aging etc. (so realistically, despite some enthusiasm, I am unlikely to be an Olympic athlete in 5 years time). Many of these constraints may be available in personal or non-personal semantic memory (see also Martin-Ordas, Atance, & Louw, 2012). But equally the imagining could involve an alternative present (what might my life be now if I had accepted that job?) which lies outside the scope of MTT as it involves traveling to an alternative reality. Thus temporal information is not an absolute requirement for such tasks but constructing scenes is. In this respect it is interesting to note that an fMRI study which examined the regions activated by recollection and episodic future thinking suggested that those regions activated by both tasks (and more than a control task) were those regions commonly associated with visuo-spatial context (Szpunar, Watson, & McDermott, 2007). Crucially, this view of episodic memory and future thinking as sharing a basis in constructing a scene which differs from the current reality removes any need for the concept of MTT or, slightly paradoxically, any absolute requirement for the concept of time in consideration of past and future events.

There is a clear connection between the constructive view of episodic memory and future imagining in humans and the hippocampally-dependent what–where–which occasion work on episodic(-like) memory in rats (Eacott et al., 2005; Eacott & Norman, 2004; Easton et al., 2009). Both reject any notion of MTT and self projection into the past or future but rely instead on viewing episodic memory as being a reconstruction involving a spatial arrangement of entities/objects within a scene other than as currently experienced. Indeed, this work also has many linkages to Gaffan's view of episodic(-like) memory in monkeys as a reconstructed snapshot (Gaffan, 1994). Gaffan (1994) reported that monkeys learning two-choice object discriminations were much faster to learn these when the objects were presented in fixed locations on distinctive background scenes. Moreover, this advantage for these scene-based discriminations was removed by lesions within the hippocampal system. Therefore, only when the discrimination could be solved using the full scene (and fulfilled the episodic criterion of what–where–which occasion), was it dependent on the hippocampal system. Gaffan (1994) argued that the discriminations with fixed locations within a distinctive background allowed the animals to reconstruct a scene of their previous experience and therefore more efficiently recall the previous reward outcomes associated with the discrimination. As a result, learning in this task was almost one-trial and in this way also resembled episodic memory. However, importantly the task contained no explicit temporal element. This work from both rats and monkeys supports the evidence from human amnesic patients and fMRI discussed above that such constructive processes are reliant on the hippocampus.

However, there is less direct evidence on future thinking in non-human animals and the link to the hippocampus. The most widely cited and accepted evidence of future thinking in non-human animals is the work of Clayton and colleagues with scrub jays (Correia et al., 2007; Raby et al., 2007) but there are no lesion data on these birds, although there is suggestive evidence that these highly skilled birds have a relatively large hippocampal volume which may be related to their abilities (e.g. Clayton, 1998; de Kort & Clayton, 2006; but see Rattenborg & Martinez-Gonzalez, 2011). Nonetheless, the evidence of future planning in these birds could be viewed from a constructive viewpoint although it by no means rules out other interpretations: caching in the relevant sleeping chamber necessitates constructing a scene of the relevant sleeping chamber and the available to-be-cached food in the context of the associated, but as yet absent, breakfasts that will available in the morning. Indeed, it may be relevant that this successful demonstration of future thinking in scrub jays involved many of the components of the to-be-constructed scene present at the caching point: only the future breakfast options were missing and needed to be added from memory, and these were strongly associated with the presence of the sleeping chambers. This may aid future thinking by cuing some of the components of the scene to be constructed. In a recent investigation into future thinking in rats from our own laboratory (Eacott, Stewart & Easton, unpublished data) which was modeled on the successful study of Clayton and colleagues (Raby et al., 2007), the future scenario was not directly cued (i.e. very few of the to-be-constructed elements were present) at the critical choice point. Rats had learned to expect a sequence of events which would end in presentation of flavored food sufficient to sate the rats. The flavor of food to be presented was cued by elements of the sequence of events (e.g. starting the sequence by being placed in context A signaled that later in the sequence food A would be available in context A, while starting the sequence in context B signaled the later availability of food B in context B). Crucially both sequences shared some elements (i.e. both context A and context B were followed in the sequence of events by the shared context C before food was finally available in the starting context). On probe trials, the rats were given unexpected opportunities to choose between food A and B in the neutral chamber C within a sequence. The situation is similar to that presented to scrub jays in that the animals had experience which would allow them to expect the near-future availability of a particular food-type and had an opportunity to choose between these food-types. A rat planning for the future might reasonably maximize variety (Rolls et al., 1981) by choosing to eat the food which differed from that which was shortly to be available in abundance, in the same way that scrub jays chose to maximize breakfast variety by caching the different food-type (Raby et al., 2007). However, unlike the scrub jays, the rats did not demonstrate evidence of future thinking. They failed to preferentially consume the food which differed from that which would shortly be available (i.e. they did not choose food A over B in a sequence which had signaled B would shortly be available and vice versa). This apparent difference between the demonstrated abilities of rats and scrub jays could have many possible explanations, including species differences and problems with task design. It is certainly true that even as a species undoubtedly able to envisage future scenarios, humans do not always appear to make choices based on foreseeable outcomes, even within the confines of a short laboratory task (e.g. Bone, Hey, & Suckling, 2009). Thus such negative findings should not be considered strong evidence that rats cannot, given an appropriate task, engage in future thinking. Nonetheless it may be considered that an ability to mentally reconstruct a future scenario based on items and contexts which are not currently present in their immediate environment (as in the rat task) might provide the purest test of future thinking and that examples using items which are available in the present (as is mainly the case in the scrub jay task) might provide a scaffolded stepping stone to such high level abilities.

If future thinking can be viewed as construction of a scene involving familiar elements which differs from the present experience, this may suggest other ways of studying such thinking in non-human animals. Just as studies with humans do not necessarily involve future events but can study the construction of imagined scenes, so work with non-human animals has also considered tasks which necessitate the flexible reconstruction of known elements into a novel but plausible form (Dusek & Eichenbaum, 1998; Eichenbaum & Fortin, 2009). Thus rats learned through experience a number of paired associates such that A should be chosen over B, B chosen over C, C chosen over D, and D over E. Once these discriminations were learned to criterion, there were probe trials which tested untrained combinations. The critical test was B vs D, as both B and D had been rewarded (B vs C; D vs E) and unrewarded (A vs B; C vs D). However, by a process of transitive inference, it can be deduced that B is to be chosen over D. Sham operated rats made this inference, performing on the B vs D trials at similar levels as they did the equivalent trained pairs. However, this ability was based on hippocampal function, as animals in which the hippocampus had been disconnected performed at chance levels on the untrained pairs that required transitive inference. Crucially, the hippocampal animals performed at normal levels on the trained pairs (Dusek & Eichenbaum, 1998). One interpretation of this result is that the probe trials required flexible use of the information from the known pairings (B over C; C over D) to construct a novel scenario (the outcome of B vs D). Interestingly, as in the successful demonstration of future thinking in scrub jays, many of the elements to be constructed were present at the critical test (B vs D) and again this may have aided the process.

Conclusions

The concept of mental time travel originally bound together work on episodic memory for past events and work on thinking about personal future events. However, we have argued that the concept of mental time travel involves subjective phenomena such as consciousness and therefore puts unhelpful and ultimately needless constraints on work on episodic memory and future thinking. On this basis we argue that mental time travel is an unhelpful concept in such work. An alternative view of scene construction has recently emerged which can more usefully bring together work on both episodic memory for past events and thinking about future or fictitious events and moreover can bridge work in humans and non-human animals. Such a view does not necessitate a concept of mental time travel and thus time travel itself may remain a fiction (Wells, 1895).

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