Review

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The comparative study of mental time travel

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People regularly travel through time mentally to remember and reconstruct past events and to anticipate and plan future events. We suggest that a bi-cone structure best describes human mental time travel (MTT) abilities. Experiments with scrub-jays, rats and non-human primates have investigated whether MTT is uniquely human by examining the abilities of these animals to remember what, where and when an event occurred and to anticipate future events. We argue that animal memory for when an event happened must be distinguished from memory for how long ago it happened to properly evaluate parallels with human capabilities. Similarly, tests of future MTT in animals must show that they are planning for a specific time in the future to demonstrate qualitative comparability with human MTT.

Human mental time travel

Although most adults would readily agree that they remember past events and anticipate future ones, only relatively recently have scientists focused on the processes responsible for this ability to mentally time travel. It is widely agreed that mental time travel (MTT) is dependent upon two systems of declarative memory; episodic memory and semantic memory [1,2]. Tulving [3] originally distinguished between episodic and semantic memory; episodic memory is memory for past episodes, whereas semantic memory is memory for general information that is not part of our personal experience, such as the countries that form the European Union. Although Tulving [3] originally suggested that memories which contained what, where and when (www) information were episodic in nature, he later suggested that these memories had the property of 'autonoetic consciousness', or the conscious re-experiencing of oneself in the remembered event, forming the basis for self awareness [4].

More recently, theorists have emphasized the importance of episodic and semantic systems for future anticipation and planning [5,6]. By drawing on information stored in episodic and semantic memories, elaborate mental scenarios describing both the past and the anticipated future can be constructed. Thus, MTT is seen as highly integrative and constructive. A person could remember his/her autobiographical history by integrating remembered past episodes with semantic information provided by relatives, friends and history books. Based on this constructed memory of the past, an individual can plan different courses of future action and anticipate their consequences. Suddendorf and Corballis [2] have argued that the ability to plan for the future based on past experience provided the primary selection pressure for the evolution of brain structures responsible for human MTT into both past and future. Schacter *et al.* [1] recently advanced the 'constructive episodic simulation hypothesis', which suggests that episodic memory and its use to simulate future episodic events are based on a common neural core network.

Studies of the distribution of numbers of autobiographical memories and anticipated events in time indicate that they decline from the present moment as a power function of past and future time [7–9]. A log–log plot of generated mental events against time declines linearly into the past and future. In addition, past and future mental episodes near to the moment when they are generated have greater clarity and sensorial detail than those more distant in time [10–13]. We attempt to capture these relationships in Figure 1 as a bi-cone, two cones that meet at their wide ends, one cone for the past and the other cone for the future. At the intersection of these cones lies the present moment in time, containing a physically present human mental time traveler. The lengths of the cones depict time, with the past cone extending back to a person's earliest memories of childhood (3–5 years of age) and the future cone extending to a point where an individual anticipates old age and death. The span of the bi-cone thus encompasses a person's entire life in mental representation. These lengths of the individual cones will change over time, with the length of the past cone elongating and the length of the future cone shortening as a person grows from childhood to adulthood and old age [9]. The width of these cones represents the amount of detail the mental time traveler has about events that have occurred or will occur at different times. Memories for different aspects of a person's life will be placed in different segments of the cone extending from the centre to the circumference, in keeping with the observation that we remember more about things we experienced yesterday than about things we did last week and more about what we experienced last week than what we did a year ago. Similarly, our plans for what we will do in the forthcoming week are many and detailed, whereas those we have for years to come are only few and more vague and general. The bi-cone is a general depiction of MTT, from which individuals vary. For example, people show a reminiscence bump or increase in autobiographical memories for events between 10–30 years of age [8], and particularly important or emotional memories from any time in the past might be well remembered [14].

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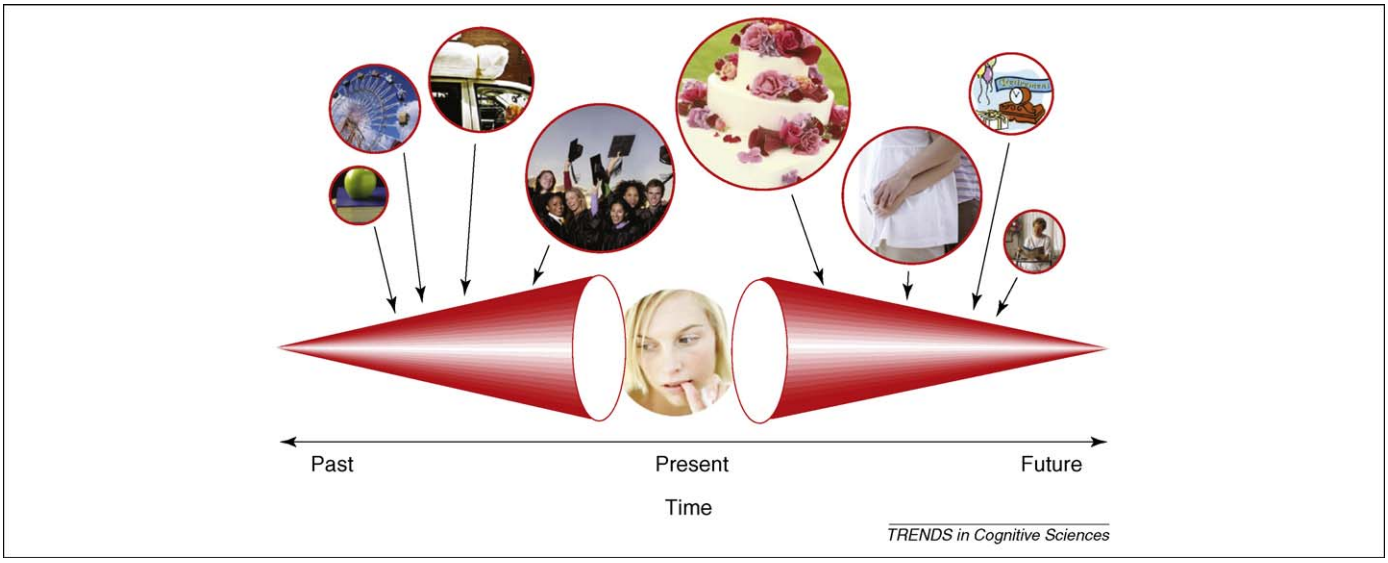

Figure 1. The bi-cone shows a mental time traveler in the present moment who can both remember past episodic memories and plan future events. The circular balloons show memories or planned events at varying temporal distances into the past or future. The size of these balloons represents the number and clarity of these memories or plans. Although individuals show bulges in the cone for particularly memorable periods in their past, the bi-cone represents the pattern of human MTT [7–13].

MTT in animals?

A debate has arisen over whether we should extend MTT to non-human animals (hereafter referred to as animals). Tulving [15–17] has argued that only humans possess episodic memory and the ability to anticipate the future, and this position has been amplified by Suddendorf and colleagues [2,18,19]. Roberts [20–22] borrowed a phrase from Vonnegut's novel 'Slaughter-House Five' (23) to suggest that animals might be 'stuck in time'. What does the stuck-in-time hypothesis mean? It means that animals might live in a permanent present, with no concept of a time dimension that extends into a past and future from the present moment. Without a sense of extended time, their episodic memory and ability to anticipate the future would be severely limited.

When confronted with the stuck-in-time hypothesis, most people immediately raise objections. Dogs clearly remember tricks taught in the past and anticipate their daily chow by going to the food dish at feeding time. It should be made clear that the stuck-in-time hypothesis does not suggest animals have no memory or that they are insensitive to time. A rat trained to press a lever for food pellets will press the bar readily at some later opportunity, showing that it has memory based on past training. However, this memory could be semantic and not episodic. That is, the rat can know that pressing the lever leads to food delivery without having any representation in memory of a specific past instance in which it has pressed the bar and been rewarded. Animals are sensitive to time of day, as shown by experiments in which they learn to go to a specific place for food at a specific time when food becomes available at that place [24–26]. Circadian rhythms enable animals to show time-place learning. That is, a fixed state in the daily cycle of internal hormonal and neural changes within an animal can be used as a cue for the arrival of food. Rats and pigeons can accurately time the interval between a cue and the delivery of food [27,28]. Models of timing based on the accumulation of neural pulses [29,30] or an animal's own behavior [31] explain such interval timing. None of these observations requires us to assume that animals have a concept of time as depicted in Figure 1 that extends over days, weeks, months and years.

Animal studies of episodic-like memory

What should be clear from these observations is that tests of the stuck-in-time hypothesis require special experimental designs that test animals' ability to detect when things happened in the past or will happen in the future. Recently, researchers have begun to develop such designs and carry out tests with different species of animals. Best known are studies by Clayton and Dickinson [32–35] that capitalize on the tendency of scrub-jays to cache and later recover food. Jays were allowed to successively cache two types of food in different locations, highly preferred wax worms and less preferred peanuts. On repeated tests, the birds were allowed to recover these foods either 4 h or 5 days later. Of crucial importance, worms became inedible after 5 days but not 4 h, whereas peanuts remained edible after both intervals. Jays rapidly adopted the strategy of visiting worm locations before peanut locations after 4 h but visiting peanut locations before worm locations after 5 days. It was argued that scrub-jays remembered not only where they had stored foods of each type but also when in the past they had stored them, thus allowing them to search strategically for preferred worms first when they were fresh but less preferred peanuts first when worms had decayed. Based on this discovery, it was argued that scrub-jays formed episodic-like memories. Episodic-like memory met the behavioral criteria of www memory, originally suggested by Tulving [3] but was episodic-like because the introspective property of autonoetic or personal consciousness later introduced by Tulving [4] could not be accessed in an animal. Thus, scrub-jays might be displaying a type of memory that has some but not all of the properties of human episodic memory. Recently, Zinkivskay *et al.* [36] have reported evidence of www memory in another corvid species of bird, the magpie.