Of course, we cannot say with any confidence that this "recall" in a rat was associated with the phenomenological experience that accompanies recall in humans. Yet, as S&C point out, there is as yet no agreement as to how to study such subjective phenomena in humans, and so we should not set the evidential bar for demonstrating recall in rats so high that it cannot be satisfied even for other humans. Nevertheless, by showing increasing evidence for similarity between phenomena in rats and in humans, we can at least claim that we have demonstrated a dissociation between "familiarity-like" memory and "recall-like" memory in the rat.

The meaning of "time" in episodic memory and mental time travel

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Abstract: The role of time in episodic memory and mental time travel is considered in light of findings on humans' temporal memory and anticipation. Time is not integral or uniform in memory for the past or anticipation of the future. The commonalities of episodic memory and anticipation require further study.

Temporal information plays a central role in discussions of the nature of episodic memory (EM) (e.g., Tulving 1972; 1984; 2002b) and mental time travel (MTT) (target article). For this reason it is important to analyze the meaning of time in EM and MTT and to consider psychological research about memory for time and ways of thinking about the future. Among the different types of temporal information that humans and animals could process are: when an event occurred (or is expected to occur) within some time pattern ("temporal locations"), how long ago an event occurred ("temporal distances"), and before–after relations and other relations of the order of events (see Friedman 1993). Multiple representations and processes are involved in humans' memory for the times of past events and in their thinking about the times of future events (Friedman 2001; 2003). The impression we sometimes have that time is a seamless, linear continuum is at odds with the findings of research on temporal abilities and the processes that underlie them (Friedman 1993). For example, memory for time is often inaccurate, systematically distorted, and even inconsistent with remembering time in an integral way – we sometimes remember the time of day of an event but not the month or year.

Adults' sense of the times of past events depends mainly on inferring when the event must have happened by relating the content of the memory to one's general knowledge of personal, conventional, and natural time patterns. But adults, as well as children as young as 4 years, also have available impressions of the ages of events that provide limited information about their distances in the past (Friedman 1996; 2001). A differentiated sense of the future depends on mental representations of time patterns, probably supplemented from early childhood onward with propositions that are active in memory (e.g., that particular events are coming soon or won't happen for a long time) (Friedman 2003). This patchwork of processes, and the fact that humans remember and anticipate times separately on multiple time scales, reveals the complexity of memory for and anticipation of the times of events.

What temporal abilities are necessary to possess EM? At various stages in the development of his theory, Tulving referred to the following as critical features: temporally dated events (though not in conventional time units; Tulving 1972), coding the temporal relations among experienced events (Tulving 1972; 1984), and having a subjective sense of time (Tulving 2002b). Others have pointed to different time-related criteria (e.g., the ability to discriminate recent from remote events [de Kort et al. 2005] or the capacity to replay the flow of experience [Eichenbaumet al. 2005]), or they have maintained that temporal information is not necessary (Suddendorf & Corballis [S&C] in the target article; Zentall 2005). In light of research on memory for the times of events, S&C's and Zentall's positions may be the wisest, at least for describing human memory. There is no evidence that events are automatically coded by the times of their occurrence or that memory is temporally organized (Friedman 1993; 2004); many older events are difficult to discriminate by their ages (e.g., Friedman & Huttenlocher 1997) but are still presumably EMs; and it seems likely that we are poor at remembering the internal order of some EMs. It might be best to think of the relevant quality of EM as experiences that are remembered as occurring on a particular *occasion*.

In MTT, what does it mean to say that one is traveling through time? The metaphor can unintentionally imply a unity and continuity of time that is quite at odds with the fragmentary, manifold way humans experience it. The finding, mentioned earlier and cited by S&C, that adults sometimes remember the time of day of an event but not its time on longer scales, is difficult to reconcile with the metaphor of "traveling through time." The limitations of this metaphor may be even clearer when one considers related developmental research. From about 4 years of age onward, many children are able to recall unique happenings when asked about events such as "your last birthday" or "last Christmas," but this ability appears years before children are aware of when these events had occurred relative to one another (Friedman 1992). What appear to be genuine EMs are more like "islands in time" than memories one reaches by mentally traveling through some temporally organized representation. Similarly, children anticipate particular events (and plan for them) before they have a clear understanding of when in the future the events will occur (Friedman 2003). Finally, 5-year-olds, who can remember specific past events and anticipate specific events to come, sometimes confuse the past–future status of these events (Friedman 2003).

Research on humans' memory for times and on thinking about the times of future events shows that there are some common processes (e.g., the use of representations of time patterns) and some differences (using impressions of the ages of memories). In my view, it remains an open question to what extent common processes underlie EM and future-directed thinking in general. The developmental and neurological evidence that S&C cite is suggestive, yet developmental changes can co-occur but be rooted in different processes, and the deficits that hippocampal patients show in EM and anticipation could be due in part to problems other than the capacity to engage in MTT (such as ones related to constructing spatially coherent representations; Hassabis et al. 2007). Even if temporal information is not a defining feature of EM, as I and others have suggested, it is not clear that the remaining criterion – autonoetic consciousness of particular autobiographical episodes – is necessary to flexibly plan specific future events. Throughout development, planning may rely to a greater extent on information abstracted from repeated episodes (the commonalities of which are more relevant to the future than the particularities) and from semantic memory. S&C have raised interesting questions which merit further research.

Mental time travel sickness and a Bayesian remedy

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Abstract: Mental time travel is a principled, but a narrow and computationally limiting, implementation of foresight. Future events can be predicted with sufficient specificity without having to have episodic memory of specific past events. Bayesian estimation theory provides a framework by which one can make predictions about specific future events by combining information about various generic patterns in the past experience.

Suddendorf & Corballis argue persuasively that the ability to foresee future "situations" is likely to depend on many different mental faculties, including memory of the past. But despite recognizing the complexity of the prediction process, the authors focus on a surprisingly narrow and problematic mechanism for it, namely, mental time travel.

As the authors formulate it, mental time travel essentially treats future as a version of the past: What one is able to "pre-live" about future events are those that one can relive about past events (target article, sect. 1, para. 1). The authors suggest that episodic memory helps "pre-live" future events, because it is this type memory that one needs for reliving the past. The key assumption here is that one can mentally create only those future events that one has specifically experienced in the past.

I contend that this is an unnecessarily narrow formulation of foresight, because one can obviously mentally create events that are sufficiently different from any that one has experienced before. The authors' formulation is also severely limiting because, if it were strictly true, it would mean that one would be able to foresee only those events that one has episodic memory of.

From the computational standpoint, it is clear that specific predictions about future events can, in principle, be made by using generic prior knowledge in a combinatorial fashion (see Glymour 2002). Information about the particularities of specific past events, such as that provided by episodic memory, is not needed. To cite a qualitative example, in order to foresee the possibility that I may be mugged if I walk through certain blocks of the city at night, I do not need the actual experience of having been mugged there at night. A general knowledge of risky time periods and risky neighborhoods is enough. This is because one can easily generalize and extrapolate, with arbitrary specificity and detail, from past experience. Thus, in the above example, one can not only foresee the *possibility* of being mugged, but also envisage the mugging event itself in arbitrary detail. Indeed, one can also vividly imagine events that one is certain never to have experienced in the past, such as a boulder rolling *up* a hill on its own. The point is that the authors' formulation of foresight ultimately amounts to placing patently untenable limitations on one's very ability to imagine.

Extending the authors' formulation of foresight to its logical limits, while perhaps not altogether fair to the authors, is nonetheless a useful exercise, because it reveals an instructive conundrum. To the extent that one can only foresee those future events that one has experienced in the past, and to the extent that events never repeat themselves exactly, one can never apply the memory of any past event to a future situation. Presumably, the authors would address this conundrum by allowing for some level of generalization and extrapolation, so that the future event does not have to be an exact replica of the past one. But that is precisely my point, too: Some degree of generalization and extrapolation is a prerequisite for predicting future events. But why limit it as severely and arbitrarily as the authors do?

The aforementioned logical exercise reveals another related, but more severe, computational limitation of the authors' formulation. Without the ability to extrapolate from generalities, the amount of particularities the brain would have to store would be subject to a combinatorial explosion. For every prediction of a future event, the memory of a corresponding past event would be needed. Conversely, what one can predict about the future will be limited by one's episodic memory. In the aforementioned mugging example, in order to foresee a mugging event, I would have to have the memory of having been previously mugged by the same person, and in the same city block, and so forth.

Again, the authors would presumably address this handicap by allowing some generalization across, and extrapolation from, past experiences. Doing so would, among other things, recognize that the various types of memory are not quite as distinct, and independent, from each other as one might think. That is, different forms of memory might interact with each other and with other mental faculties to help foresee the future. Although the authors allude to this possibility initially, they move away from it later, especially in rejecting several possible instances of foresight in nonhuman animals simply because they do not appear to involve episodic memory (target article, sect. 3).

Note that in terms of its amenability to generalization and extrapolation, episodic memory is the least suitable form of memory. That is, episodic memory by itself is a computational bottleneck. Therefore, other types of memory must play a major role, and mental time travel must play a correspondingly smaller role, in foresight.

The Bayesian estimation theory encapsulates the aforementioned general computational principles into a powerful and flexible framework for making predictions. Briefly, in this framework, prediction is a fairly straightforward extension of parameter estimation. The future value of a given parameter can be estimated by combining the relevant probabilistic information about the past and present values of the parameter (for more rigorous expositions, see Davidson & Wolpert 2005; Glymour 2002; Krauth 1983). Three features of the Bayesian framework are especially worth highlighting in this context. First, this framework is clearly biologically plausible. Second, in many cases, Bayesian prediction can be shown to be ideal. Third, the Bayesian framework is versatile, in that it can use all available relevant information, including different forms of memory, to arrive at a prediction. Thus, the Bayesian framework can utilize episodic memory, but is not dependent on it. In this sense, the Bayesian framework subsumes, and greatly extends, the authors' framework for foresight.

Of course, the Bayesian framework for prediction has its faults and limitations (see, e.g., Krauth 1983). But it represents, at a minimum, a substantive counterexample to the framework suggested by the authors.

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Past and future, human and nonhuman, semantic/procedural and episodic

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Abstract: The overlap of representations of past and future is not a completely new idea. Suddendorf & Corballis (S&C) usefully discuss the problems of testing the existence of such representations. Our taxonomy of memory differs from theirs, emphasizing the late evolutionary emergence of notions of time in memory.

The target article makes a useful contribution. We offer some reservations that do not undermine its central purpose.