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Prospection and natural selection

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Prospection refers to thinking about the future, a capacity that has become the subject of increasing research in recent years. Here we first distinguish basic prospection, such as associative learning, from more complex prospection commonly observed in humans, such as episodic foresight, the ability to imagine diverse future situations and organize current actions accordingly. We review recent studies on complex prospection in various contexts, such as decision-making, planning, deliberate practice, information gathering, and social coordination. Prospection appears to play many important roles in human survival and reproduction. Foreseeing threats and opportunities before they arise, for instance, drives attempts at avoiding future harm and obtaining future benefits, and recognizing the future utility of a solution turns it into an innovation, motivating refinement and dissemination. Although we do not know about the original contexts in which complex prospection evolved, it is increasingly clear through research on the emergence of these capacities in childhood and on related disorders in various clinical conditions, that limitations in prospection can have profound functional consequences.

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Introduction

The future matters. Present actions can influence the chances of survival and reproduction, and thus natural selection has produced mechanisms that increase the likelihood of future benefits and decrease the likelihood of future harm (e.g. [1,2]). Most species are attuned to important long-term regularities such as fluctuations of light, temperature and food availability that are tied to daily and annual cycles. Perhaps most conspicuously, as cold winter months approach some species prepare for food scarcity by hoarding. Organisms that adapt effectively to recurrent fluctuations outbreed those that do not. Even *Escherichia coli* bacteria, when travelling through human digestive tracts, switch on genes for maltose digestion ahead of reaching the maltose-rich section [3]. However, many significant environmental features do not change cyclically. Contingencies change; sometimes very rapidly. Thus, natural selection has also favoured mechanisms that enable animals to adjust their behaviour to new, local regularities. Animals can learn; and thus predict.

Here we were asked to discuss prospection, defined as 'thinking about the future', and its relationship to survival. We will first discuss fundamentals common to many species, before considering the fitness consequences of the human capacity to consider diverse and remote future possibilities (for a recent review of studies on the neurocognitive mechanisms see [4]).

Basic prospection

Associative learning

Some adaptive flexibility can be achieved by a capacity for developmental parameter-setting during critical periods, and other types of individual learning. In fact, all associative learning may be regarded as future-oriented mechanisms that enable individuals to track local regularities and adapt their behaviour so as to increase the chances of future rewards and avoidance of punishments [5]. Animals equipped with a capacity for positive and negative states (e.g. pleasure and pain) may prospectively guide actions by learning about their immediate antecedents: when the learned antecedents recur, the animal can predict imminent reward or punishment, and drive action before these become manifest.

It may be questioned whether such learning really involves any representation of the future situation and hence should be classified as prospection. Early theorists such as Thorndike suggested that organisms simply learn associations between stimulus and response, leaving the reinforcer as mere catalyst [6]. However, it later became evident that the reinforcer can be part of the associative network, and its evaluation can change [7]. Animals not only learn that certain actions are rewarding in particular circumstances, but that those actions also lead to specific kinds of outcomes. In other words, instrumental actions can be goal-directed and considered a form of prospection. When expectations are not met, animals often change their behaviours accordingly. For instance, primates reject to work for a less-preferred food once they see another individual receiving a preferred food for the same work [8], or once they have noticed that the experimenter is not rewarding them as well as they could [9••]. In other words, the animals demonstrate 'disappointment' when they do not get what they expect.

In their influential approach, Rescorla and Wagner modelled Pavlovian learning on the basis of such a mismatch between the animal's expectation and the reality that unfolds, for when expectations are met there is little for the animal to learn [10]. From this perspective, prospection is not only guided by what the animal knows, it also plays a critical role in learning itself (see Box 1 for a relevant discussion in the context of navigation). Recent work conceptualizes the disjunction between expectation and experience as also playing an important role in more complex prospection, and in neural and cognitive processing more broadly, although many important open questions remain about the ability of such 'predictive processing' accounts to effectively integrate observations at various levels of analysis [11–13,14••,15,16].

Complex prospection

Associative learning enables prediction of what happens next. Aside from rare cases such as taste aversion [17], learning tends to build on immediate antecedents and expectations tend to be about instant consequences. Contiguity between events is critical for associative learning, and even a hiatus of minutes, let alone hours or days, typically makes learning of associations between events impossible. Furthermore, these expectations appear to be fixed to specific pairings and so do not lend themselves to more complex prospection, such as consideration of multiple, mutually exclusive possibilities that may occur. A human hunter may prepare a trap for several potential exits his prey may try to take from its hideout. By contrast, even our closest animal relatives, great apes, appear to struggle preparing for two simple alternatives (see Box 2).

Perhaps uniquely, humans can consider many, even remote alternative future scenarios, and embed them into larger narratives [18]. Even if we have never experienced the situation before, we know that one career choice has different consequences than another, or that following the suggestion to play a game involving crossing a street blindfolded is a bad idea. People think about future events often and tend do so with optimism [19,20] (though there are cultural differences [21,22]). Even though we are often not quite accurate in what we predict, we endlessly entertain options and evaluate them in terms of, for instance, their likelihood and potential consequences, and these thoughts guide our actions [23]. This capacity to flexibly travel in our minds into the future and organize current actions accordingly may be referred to as 'episodic foresight' [24] (we prefer this label over the phrase 'episodic future thinking' partly because its counterpart is 'episodic memory' and not 'episodic past thinking'). We maintain that episodic foresight has given our ancestors a tremendous adaptive advantage over creatures with more limited prospection, as it enabled them to prepare for dangers and to seize opportunities before they manifested. We now describe recent research on three broad aspects of complex prospection.

Box 1 Navigation and prospection.

Animals often seek situations that harbour rewards or lead to safety by navigating based on representations of space [88,89]. Mantled howler monkeys, for instance, traverse the canopy in ways that enhance the quantity of mature fruits they can gather [90]. The underlying neurocognitive machinery of such navigation in mammals is critically dependent on the hippocampus [91], featuring a complex network of place-, grid-, border- and head-direction-cells that code spatial representations [92]. A recent computational model suggests that the hippocampus may support navigation by generating *predictions* about spatial movement [93]. Compatible with this notion, single place cell recordings in rats have identified sequences that seem to indicate simulation of future movement [94] (but see [95,96]), although debate continues about the nature and complexity of the events that nonhuman animals might be able to represent [97,98]. In fact, a key function of the hippocampus may be to guide exploratory behaviours to facilitate learning about the environment, achieved by the active maintenance of relevant memory traces [99]. Recent evidence suggests that the prefrontal cortex (PFC) is involved in influencing this type of hippocampal maintenance of relevant memories in a context-dependent manner [100,101]. The results of recent lesion studies have also been taken to suggest that a network involving the vmPFC and hippocampus is necessary for more complex prospection in humans [102].

Box 2 Preparing for mutually exclusive possibilities.

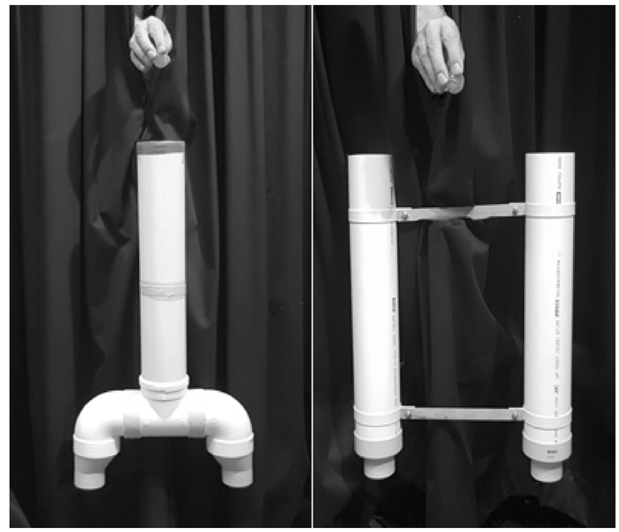
The future is uncertain and, being aware of this, humans frequently make backup plans. For instance, people may prepare what they are going to do if they pass or fail the exam, if the weather is going to be good or bad, or if the love interest does or does not say 'yes'. Contingency plans can be devised to address multiple possibilities and can involve very complex strategies. To examine the emergence of the simplest, fundamental capacity to foresee mutually exclusive outcomes of an event, Redshaw and Suddendorf devised a minimalist paradigm involving the drop of a desirable object into an upside down Y-shaped tube and giving subjects an opportunity to catch it (left panel) [87••]. Chimpanzees, orang-utans and two-year-old human children prepared by placing one hand under one of the two exits, and therefore ended up catching the reward only some of the time. Older children were more successful: by age four, most children spontaneously and consistently covered both exits from trial one onwards, assuring themselves the reward. They hence demonstrated a capacity to prepare for at least two mutually exclusive versions of an imminent future event. Some younger children, and even one chimpanzee, covered two exits on some trials, but then reverted to a one-handed response, suggesting a lack of insight. In a recent follow-up study, young children and chimpanzees showed a similar pattern of responses when presented with a situation involving two parallel tubes and an experimenter who simply dropped the target into one of them (right panel) [103] (Figure 1).

Considering possibilities

Options can be evaluated and compared [25] based on mental simulations of these events as if they were currently happening [26,27]. The feelings that are evoked during these simulations are referred to as affective forecasts [28], and play an important role in motivating future-directed behaviour [29,30]. For instance, affective information derived from simulations can influence decision-making in the context of intertemporal choices where future and present rewards must be weighed up [31,32]. Relatedly, recent evidence suggests imagining goal-related episodic future events can attenuate delay discounting [33], reduce calorie consumption in overweight people [34] and reduce aspects of alcohol demand [35,36] (also see [37,38]). Relatedly, a mentally simulated future danger may evoke feelings associated with an emotional fear or anxiety response instead, and this may provide the motivational currency to spur appropriate defensive behaviour in the here-and-now [39,40].

Mental simulations of the future can thus also support the encoding of options [41–43], for example intentions to be deployed at a later time (i.e. so-called 'prospective memory') [44–46]. Another critical advantage of the capacity to encode possibilities is that this allows one's mental model of a future scenario to be updated in the light of new information before action is taken. This may help explain why humans prospect so frequently, and often involuntarily [47–49], and why mental simulations of the future tend to cluster around personal goals [49–52]. In a dynamic world, episodic foresight is most effective if it involves repeated mental trial and error, monitoring and reflection, so that solutions to anticipated future scenarios can be fine-tuned and adjusted to avoid dangers and capitalize on opportunities. To date, however, episodic foresight has mainly been studied with single time point measures in more static contexts.

Figure 1



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The apparatus used to assess preparation for two possible event outcomes, either caused by a hidden mechanism (**left panel** [87••]) or by an experimenter rapidly dropping the target into one of the parallel tubes (**right panel** [103]).

Social exchange

Language enables humans to refine their foresight through others' experiences, predictions and reflections. We ask questions and give each other advice about what to expect [53]. Humans have a fundamental urge to exchange mental scenarios and insights [18,54]. Such exchanges often concern functionally relevant information, such as about potential future threats [55••]. Through exchange of experiences, reflections and plans, we humans have been able to coordinate our cooperative activities in ever-more powerful ways [18], and researchers are beginning to separately examine personal and collective future thinking (e.g. [56,57]). Communication about future scenarios can lead us to abandon, amend or solidify plans or intentions, or to create new ones in light of the acquired information. The regularity of such exchanges suggests that there may have existed selective pressures on those who failed to collaborate [58], as well as on the inability to distinguish co-operators from defectors, and information that could help from information that misleads [59].

We argue that complex prospection is a quintessential human survival mechanism [60,61], and that humans all incessantly benefit from the foresight of others, allowing us to deal with problems before they arise and to shape the future to our design. Consider tools, upon which much of this prudent preparation depends. Humans innovate. We can imagine the functionality and aesthetics of the things we make before we make them, or we may try a small-scale version before investing into a large project. Regardless of whether we have creatively figured out a solution to a problem or merely stumbled upon it by accident, what turns the solution into 'innovation' is the recognition that it has future utility (i.e. prospection) [62]. Once we realize a tool has future utility, we are motivated to retain the solution so we can use it again, to spend time improving it, and to share it with our friends (or sell it). Whereas many species use tools and some even make them, only humans seem to keep them, refine them, and share them. Our solutions become better as tool kits and options accumulate and spread through a population. We can all benefit when people with better or complementary sets of skills improve existing technologies, even if such efforts are ultimately driven by the innovator's own anticipated material benefit. These processes have enabled us to establish ever more powerful toolsets that have allowed us to dominate the planet.

Shaping one's future self

We can not only shape the world by design, but even our own future capacities. Through deliberate practice — repeated actions driven by the goal to improve future capacities — we can intentionally acquire skills. This has been studied primarily in the context of elite expertise [63], but is equally critical to how we all acquire more basic skills, such as tying shoelaces [64]. Similarly, we deliberately seek information that we consider will be useful to future situations, or cultivate metacognitive strategies to overcome our own mental shortcomings (e.g. by setting ourselves reminders to deal with our forgetfulness). Metacognition and episodic foresight are inextricably intertwined: one must be aware of one's current limitations in order to identify the appropriate route towards improvement [65,66,67•]. Together, these strategies enable us to become knowledgeable and proficient in areas we select, and the fact that people can make vastly different choices about what matters goes some way to explaining why humans are so tremendously diverse in their expertise [18].

Humans acquire deliberate practice, information search and reminder setting capacities gradually in childhood [68,69]. As these capacities emerge, adults may begin to prompt young children to pursue certain types of expertise over others. However, even without instruction or other external prompts, we can autocue practice based on our own simulations [70]. Humans regularly spend thousands of hours practicing skills that they or others believe to be worthwhile improving, and much of this is critical to our survival and reproductive success.

The costs of complex prospection

The capacity to think ahead also comes with tremendous costs. Learning to prudently prospect is resource intensive and competence develops only gradually [70,71]. Worse still, we often fail to foresee significant events and our predictions are often wrong. Even when we foresee roughly correct outcomes, we are often inaccurate in terms of specifics [28]. For instance, we tend to mispredict the extent to which future events will have an impact on the way we will feel [72]. This has costs to our wellbeing, as does the fact that we repeatedly think about future problems that we can do little about [47,73]. Prospection confronts us with unwelcome facts such as our own mortality [74] and with problems that may appear insurmountable. Although the ability to anticipate and prepare for future threats is probably a key adaptive component of threat management in humans [40,75–77], it can bring to mind profound and persistent concerns. The current generation, for instance, is increasingly becoming aware about the diverse global, long-term consequences of our collective behaviour that individually we have little power to correct.

There is also a growing recognition that prospection plays a critical role in a range of common and severe psychiatric conditions, from anxiety disorders and depression to schizophrenia and suicidal tendencies [78–86]. But even the well-adjusted are often struggling to enjoy the here and now, as their minds are busy worrying about the future and trying to plot their way to happiness. As John Lennon sang: 'Life is what happens while you are busy making other plans'. The study of prospection is only still in its infancy and we foresee increasing research efforts as people recognize its profound roles and diverse consequences for our success individually and as a species.

Conflict of interest statement

Nothing declared.

References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- • of special interest
- •• of outstanding interest

1. Mobbs D, Hagan CC, Dalgleish T, Silston B, Prévost C: **The ecology of human fear: survival optimization and the nervous system**. *Front Neurosci* 2015, **9**.
2. LeDoux J: **Rethinking the emotional brain**. *Neuron* 2012, **73**: 653-676.
3. Mitchell A, Romano GH, Groisman B, Yona A, Dekel E, Kupiec M, Dahan O, Pilpel Y: **Adaptive prediction of environmental changes by microorganisms**. *Nature* 2009, **460**:220-224.
4. Schacter DL, Benoit RG, Szpunar KK: **Episodic future thinking: mechanisms and functions**. *Curr Opin Behav Sci* 2017, **17**:41-50.
5. Suddendorf T, Corballis MC: **The evolution of foresight: what is mental time travel, and is it unique to humans?** *Behav Brain Sci* 2007, **30**:299-313 (discussion 313–351).
6. Thorndike EL: **Expectation**. *Psychol Rev* 1946, **53**:277-281.
7. Dickinson A, Balleine B: **Causal cognition and goal-directed action**. In *The Evolution of Cognition.* Edited by Heyes C, Huber L. MIT Press; 2000:185-204.
8. Brosnan SF, de Waal FBM: **Monkeys reject unequal pay**. *Nature* 2003, **425**:297-299.
9. •• Engelmann JM, Clift JB, Herrmann E, Tomasello M: **Social disappointment explains chimpanzees' behaviour in the inequity aversion task**. *Proc Biol Sci* 2017:284.

This clever study suggests that chimpanzees who reject a less preferred food item when an experimenter previously gave a preferred food item to another individual, may do this not out of a sense of fairness, but because of social disappointment that the human did not give them the reward they expected to get. Presence of another chimpanzee did not increase food rejections, but delivery by a human did lead to more rejections than delivery by a machine.

10. Rescorla RA, Wagner AR: **A theory of Pavlovian conditioning: variations in the effectiveness of reinforcement and nonreinforcement**. *Classical Conditioning II: Current Research and Theory*. Appleton-Century-Crofts; 1972:64-99.
11. Rigoli F, Mathys C, Friston KJ, Dolan RJ: **A unifying Bayesian account of contextual effects in value-based choice**. *PLoS Comput Biol* 2017, **13**:e1005769.
12. Clark A: **Whatever next? Predictive brains, situated agents, and the future of cognitive science**. *Behav Brain Sci* 2013, **36**:181-204.
13. Bubic A, von Cramon DY, Schubotz RI: **Prediction, cognition and the brain**. *Front Hum Neurosci* 2010, **4**:25.
14. •• Pezzulo G: **The mechanisms and benefits of a future-oriented brain**. In *Seeing the Future: Theoretical Perspectives on Future-oriented Mental Time Travel.* Edited by Michaelian K, Klein SB, Szpunar KK. Oxford University Press; 2016:267-284.

Discussion of potential mechanisms underlying functional prospection as well as an attempt to draw together research on 'low-level' prediction with mental time travel.

15. Pezzulo G, Cartoni E, Rigoli F, Pio-Lopez L, Friston K: **Active inference, epistemic value, and vicarious trial and error**. *Learn Mem* 2016, **23**:322-338.

16. Pezzulo G, Rigoli F, Friston K: **Active inference, homeostatic regulation and adaptive behavioural control**. *Prog Neurobiol* 2015, **134**:17-35.

17. Garcia J, Hankins WG, Rusiniak KW: **Behavioral regulation of the milieu interne in man and rat**. *Science* 1974, **185**:824-831.

18. Suddendorf T: *The Gap: The Science of What Separates Us From Other Animals*. Basic Books; 2013.

19. Barsics C, Van der Linden M, D'Argembeau A: **Frequency, characteristics, and perceived functions of emotional future thinking in daily life**. *Q J Exp Psychol 2006* 2016, **69**:217-233.

20. Sharot T, Garrett N: **Forming beliefs: why valence matters**. *Trends Cogn Sci* 2016, **20**:25-33.

21. Joshi MS, Carter W: **Unrealistic optimism: east and west?** *Front Psychol* 2013, **4**.

22. Rose JP, Endo Y, Windschitl PD, Suls J: **Cultural differences in unrealistic optimism and pessimism: the role of egocentrism and direct versus indirect comparison measures**. *Pers Soc Psychol Bull* 2008, **34**:1236-1248.

23. Baumeister R, Vohs K, Oettingen G: **Pragmatic prospection: how and why people think about the future**. *Rev Gen Psychol* 2016, **20**:3-16.

24. Suddendorf T, Moore C: **Introduction to the special issue: the development of episodic foresight**. *Cogn Dev* 2011, **26**:295-298.

25. Suddendorf T, Busby J: **Making decisions with the future in mind: developmental and comparative identification of mental time travel**. *Learn Motiv* 2005, **36**:110-125.

26. Damasio A: *The Feeling of What Happens: Body and Emotion in the Making of Consciousness*. Harcourt; 1999.

27. Gilbert DT, Wilson TD: **Why the brain talks to itself: sources of error in emotional prediction**. *Philos Trans R Soc B Biol Sci* 2009, **364**:1335-1341.

28. Wilson TD, Gilbert DT: **Affective forecasting**. *Adv Exp Soc Psychol* 2003, **35**:345-411.

29. Damasio A, Carvalho GB: **The nature of feelings: evolutionary and neurobiological origins**. *Nat Rev Neurosci* 2013, **14**:143-152.

30. Miloyan B, Suddendorf T: **Feelings of the future**. *Trends Cogn Sci* 2015, **19**:196-200.

31. Boyer P: **Evolutionary economics of mental time travel?** *Trends Cogn Sci* 2008, **12**:219-224.

32. Bulley A, Henry J, Suddendorf T: **Prospection and the present moment: the role of episodic foresight in intertemporal choices between immediate and delayed rewards**. *Rev Gen Psychol* 2016, **20**:29-47.

33. O'Donnell S, Oluyomi Daniel T, Epstein LH: **Does goal relevant episodic future thinking amplify the effect on delay discounting?** *Conscious Cogn* 2017, **51**:10-16.

34. Dassen FCM, Jansen A, Nederkoorn C, Houben K: **Focus on the future: episodic future thinking reduces discount rate and snacking**. *Appetite* 2016, **96**:327-332.

35. Bulley A, Gullo MJ: **The influence of episodic foresight on delay discounting and demand for alcohol**. *Addict Behav* 2017, **66**: 1-6.

36. Snider SE, LaConte SM, Bickel WK: **Episodic future thinking: expansion of the temporal window in individuals with alcohol dependence**. *Alcohol Clin Exp Res* 2016, **40**:1558-1566.

37. Noël X, Jaafari N, Bechara A: **Addictive behaviors: why and how impaired mental time matters?** In *Progress in Brain Research.* Edited by Calvey T, Daniels WMU. Elsevier; 2017:219-237. (Chapter 9).

38. Bickel WK, Mellis AM, Snider SE, Athamneh LN, Stein JS, Pope DA: **21st century neurobehavioral theories of decision making in addiction: review and evaluation**. *Pharmacol Biochem Behav* 2017 http://dx.doi.org/10.1016/j.pbb.2017.09.009.

39. Boyer P, Bergstrom B: **Threat-detection in child development: an evolutionary perspective**. *Neurosci Biobehav Rev* 2011, **35**:1034-1041.

40. Miloyan B, Bulley A, Suddendorf T: **Episodic foresight and anxiety: proximate and ultimate perspectives**. *Br J Clin Psychol* 2016, **55**:4-22.

41. Martin VC, Schacter DL, Corballis MC, Addis DR: **A role for the hippocampus in encoding simulations of future events**. *Proc Natl Acad Sci U S A* 2011, **108**:13858-13863.

42. Poppenk J, Moscovitch M, McIntosh AR, Ozcelik E, Craik FIM: **Encoding the future: successful processing of intentions engages predictive brain networks**. *NeuroImage* 2010, **49**: 905-913.

43. Jeunehomme O, D'Argembeau A: **Accessibility and characteristics of memories of the future**. *Memory* 2017, **25**:666-676.

44. Terrett G, Rose NS, Henry JD, Bailey PE, Altgassen M, Phillips LH, Kliegel M, Rendell PG: **The relationship between prospective memory and episodic future thinking in younger and older adulthood**. *Q J Exp Psychol 2006* 2016, **69**:310-323.

45. Einstein GO, McDaniel MA: **Normal aging and prospective memory**. *J Exp Psychol Learn Mem Cogn* 1990, **16**:717-726.

46. Redshaw J, Henry JD, Suddendorf T: **Disentangling the effect of event-based cues on children's time-based prospective memory performance**. *J Exp Child Psychol* 2016, **150**:130-140.

47. Killingsworth MA, Gilbert DT: **A wandering mind is an unhappy mind**. *Science* 2010, **330**:932.

48. Stawarczyk D, Cassol H, D'Argembeau A: **Phenomenology of future-oriented mind-wandering episodes**. *Front Psychol* 2013, **4**:425.

49. Baird B, Smallwood J, Schooler JW: **Back to the future: autobiographical planning and the functionality of mind-wandering**. *Conscious Cogn* 2011, **20**:1604-1611.

50. D'Argembeau A, Lardi C, Van der Linden M: **Self-defining future projections: exploring the identity function of thinking about the future**. *Mem Hove Engl* 2012, **20**:110-120.

51. D'Argembeau A, Van der Linden M: **Predicting the phenomenology of episodic future thoughts**. *Conscious Cogn* 2012, **21**:1198-1206.

52. Demblon J, D'Argembeau A: **The organization of prospective thinking: evidence of event clusters in freely generated future thoughts**. *Conscious Cogn* 2014, **24**:75-83.

53. Suddendorf T, Addis DR, Corballis MC: **Mental time travel and the shaping of the human mind**. *Philos Trans R Soc B Biol Sci* 2009, **364**:1317-1324.

54. Tomasello M: *A Natural History of Human Thinking*. Harvard University Press; 2014.

55. •• Blaine T, Boyer P: **Origins of sinister rumors: a preference for threat-related material in the supply and demand of information**. *Evol Hum Behav* 2017 http://dx.doi.org/10.1016/j.evolhumbehav.2017.10.001.

Four studies find support for the idea that the cultural spread of threat-related information can be explained by preferential transmission rooted in human threat-management systems.

56. Michaelian K, Sutton J: **Distributed cognition and memory research: history and current directions**. *Rev Philos Psychol* 2013, **4**:1-24.

57. Piotr M, Szpunar, Karl K, Szpunar: **Collective future thought: concept, function, and implications for collective memory studies**. *Mem Stud* 2016, **9**:376-389.

58. Suddendorf T: **Evolution, lies, and foresight biases**. *Behav Brain Sci* 2011, **34**:38-39.

59. von Hippel W, Trivers R: **The evolution and psychology of self-deception**. *Behav Brain Sci* 2011, **34**:1-16 (discussion 16–56).

60. Michaelian K, Klein SB, Szpunar KK: **The past, the present, and the future of future-oriented mental time travel**. *Seeing the Future: Theoretical Perspectives on Future-oriented Mental Time Travel*. Oxford University Press; 2016:1-18.

61. Suddendorf T: **Foresight and evolution of the human mind**. *Science* 2006, **312**:1006-1007.

62. von Hippel W, Suddendorf T: *Did humans evolve to innovate with a social rather than technical orientation?* 2017.

63. Anders Ericsson K: **Deliberate practice and acquisition of expert performance: a general overview**. *Acad Emerg Med* 2008, **15**:988-994.

64. Suddendorf T, Brinums M, Imuta K: **Shaping one's future self — the development of deliberate practice**. In *Seeing the Future: Theoretical Perspectives on Future-oriented Mental Time Travel.* Edited by Michaelian K, Klein S, Szpunar K. 2016:343-366.

65. Redshaw J, Bulley A: **Future thinking in animals: capacities and limitations**. In *The Psychology of Thinking about the Future.* Edited by Oettingen G, Sevincer AT, Gollwitzer PM. Guilford Press; 2018.

66. Redshaw J: **Does metarepresentation make human mental time travel unique?** *Wiley Interdiscip Rev Cogn Sci* 2014, **5**: 519-531.

67. • Risko EF, Gilbert SJ: **Cognitive offloading**. *Trends Cogn Sci* 2016, **20**:676-688.
Broad review of recent research on 'offloading cognition' into the environment as an adaptive cognitive strategy.

68. Brinums M, Imuta K, Suddendorf T: **Practicing for the future: deliberate practice in early childhood**. *Child Dev* 2017 http://dx.doi.org/10.1111/cdev.12938.

69. Davis JTM, Cullen E, Suddendorf T: **Understanding deliberate practice in preschool-aged children**. *Q J Exp Psychol* 2016, **69**:361-380.

70. Suddendorf T: **The emergence of episodic foresight and its consequences**. *Child Dev Perspect* 2017, **11**:191-195.

71. Atance CM: **Young children's thinking about the future**. *Child Dev Perspect* 2015, **9**:178-182.

72. Buechel EC, Zhang J, Morewedge CK: **Impact bias or underestimation? Outcome specifications predict the direction of affective forecasting errors**. *J Exp Psychol Gen* 2017, **146**:746-761.

73. Watkins ER: **Constructive and unconstructive repetitive thought**. *Psychol Bull* 2008, **134**:163-206.

74. Varki A: **Human uniqueness and the denial of death**. *Nature* 2009, **460**:460684c.

75. Bulley A, Henry JD, Suddendorf T: **Thinking about threats: memory and prospection in human threat management**. *Conscious Cogn* 2017, **49**:53-69.

76. Miloyan B, Pachana NA, Suddendorf T: **The future is here: a review of foresight systems in anxiety and depression**. *Cogn Emot* 2014, **28**:795-810.

77. Miloyan B, Bulley A, Suddendorf T: **Anxiety: here and beyond**. *Emot Rev* 2018.

78. Henry JD, Addis DR, Suddendorf T, Rendell PG: **Introduction to the special issue: prospection difficulties in clinical populations**. *Br J Clin Psychol* 2016, **55**:1-3.

79. MacLeod AK: *Prospection, Well-being, and Mental health*. Oxford University Press; 2017.

80. Addis DR, Hach S, Tippett LJ: **Do strategic processes contribute to the specificity of future simulation in depression?** *Br J Clin Psychol* 2016, **55**:167-186.

81. Lyons AD, Henry JD, Rendell PG, Robinson G, Suddendorf T: **Episodic foresight and schizophrenia**. *Br J Clin Psychol* 2016, **55**:107-122.

82. Terrett G, Lyons A, Henry JD, Ryrie C, Suddendorf T, Rendell PG: **Acting with the future in mind is impaired in long-term opiate users**. *Psychopharmacology (Berl)* 2017, **234**:99-108.

83. Ernst A, Sourty M, Roquet D, Noblet V, Gounot D, Blanc F, De Seze J, Manning L: **Functional and structural cerebral changes in key brain regions after a facilitation programme for episodic future thought in relapsing-remitting multiple sclerosis patients**. *Brain Cogn* 2016, **105**:34-45.

84. Irish M, Piolino P: **Impaired capacity for prospection in the dementias — theoretical and clinical implications**. *Br J Clin Psychol* 2016, **55**:49-68.

85. Noël X, Saeremans M, Kornreich C, Jaafari N, D'Argembeau A: **Future-oriented mental time travel in individuals with disordered gambling**. *Conscious Cogn* 2017, **49**:227-236.

86. LeDoux J: *Anxious: Using the Brain to Understand and Treat Fear and Anxiety*. Penguin; 2016.

87. •• Redshaw J, Suddendorf T: **Children's and apes' preparatory responses to two mutually exclusive possibilities**. *Curr Biol* 2016, **26**:1758-1762.
Used a novel paradigm to measure preparation for two mutually exclusive possibilities yielding a desirable reward: whereas many 3 and 4 year olds prepared immediately and simultaneously for both alternatives, 2 year olds and great apes only prepared for one alternative at a time.

88. Menzel R, Greggers U: **The memory structure of navigation in honeybees**. *J Comp Physiol A Neuroethol Sens Neural Behav Physiol* 2015, **201**:547-561.

89. Tolman EC: **Cognitive maps in rats and men**. *Psychol Rev* 1948, **55**:189-208.

90. Hopkins ME: **Mantled howler monkey spatial foraging decisions reflect spatial and temporal knowledge of resource distributions**. *Anim Cogn* 2016, **19**:387-403.

91. O'Keefe J, Nadel L: *The Hippocampus as a Cognitive Map*. Oxford University Press; 1978.

92. Moser M-B, Rowland DC, Moser EI: **Place cells, grid cells, and memory**. *Cold Spring Harb Perspect Biol* 2015, **7**:a021808.

93. Stachenfeld KL, Botvinick MM, Gershman SJ: **The hippocampus as a predictive map**. *Nat Neurosci* 2017, **20** nn.4650.

94. Pfeiffer BE, Foster DJ: **Hippocampal place-cell sequences depict future paths to remembered goals**. *Nature* 2013, **497**: 74-79.

95. Bendor D, Spiers HJ: **Does the hippocampus map out the future?** *Trends Cogn Sci* 2016, **20**:167-169.

96. Silva D, Feng T, Foster DJ: **Trajectory events across hippocampal place cells require previous experience**. *Nat Neurosci* 2015, **18** nn.4151.

97. Corballis MC: **Mental time travel: a case for evolutionary continuity**. *Trends Cogn Sci* 2013, **17**:5-6.

98. Redshaw J, Taylor AH, Suddendorf T: **Flexible planning in ravens?** *Trends Cogn Sci* 2017, **21**:821-822.

99. Voss JL, Bridge DJ, Cohen NJ, Walker JA: **A closer look at the hippocampus and memory**. *Trends Cogn Sci* 2017, **21**:577-588.

100. Place R, Farovik A, Brockmann M, Eichenbaum H: **Bidirectional prefrontal-hippocampal interactions support context-guided memory**. *Nat Neurosci* 2016, **19**:992-994.

101. Eichenbaum H: **Prefrontal–hippocampal interactions in episodic memory**. *Nat Rev Neurosci* 2017, **18** nrn.2017.74.

102. McCormick C, Ciaramelli E, De Luca F, Maguire EA: **Comparing and contrasting the cognitive effects of hippocampal and ventromedial prefrontal cortex damage: a review of human lesion studies**. *Neuroscience* 2017 http://dx.doi.org/10.1016/j.neuroscience.2017.07.066.

103. Suddendorf T, Crimston J, Redshaw J: **Preparatory responses to socially determined, mutually exclusive possibilities in chimpanzees and children**. *Biol Lett* 2017, **13**.