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Deliberating trade-offs with the future

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Many fundamental choices in life are intertemporal: they involve trade-offs between sooner and later outcomes. In recent years there has been a surge of interest into how people make intertemporal decisions, given that such decisions are ubiquitous in everyday life and central in domains from substance use to climate change action. While it is clear that people make decisions according to rules, intuitions and habits, they also commonly deliberate over their options, thinking through potential outcomes and reflecting on their own preferences. In this Perspective, we bring to bear recent research into the higher-order capacities that underpin deliberation—particularly those that enable people to think about the future (prospection) and their own thinking (metacognition)—to shed light on intertemporal decision-making. We show how a greater appreciation for these mechanisms of deliberation promises to advance our understanding of intertemporal decision-making and unify a wide range of otherwise disparate choice phenomena.

Given that time runs in only one direction, many of the most fundamental choices in life are ones that involve trade-offs between sooner and later outcomes. The causes and consequences of intertemporal choice have received attention for centuries[1–3], but now face an increasing surge of interest. This is because intertemporal choices are ubiquitous in everyday life, but also because they characterise a wide range of societally significant behaviours, from substance use to climate change action. Accordingly, basic and translational scholarship on the phenomenon has accelerated in economics[4], clinical psychology[5], cognitive neuroscience[6], behavioural ecology[7], genetics[8], philosophy[9] and in other branches of the behavioural sciences.

One popular approach to understanding human decision-making has been to study the rules, intuitions and habits that influence it[10–12]. Often, however, people deliberate considerably when they must make trade-offs over time, thinking through conceivable payoffs and pitfalls, as well as reflecting on their own preferences. By a broad definition, deliberation is the process by which a decision-maker considers their options (Box 1). This process entails multiple stages, including representing the possible options and their subsequent outcomes, as well as evaluating these representations[13–15]. It requires a decision-maker to construct and search through the cognitive space of option–outcome paths and to thereby settle on one route forward. Whether there are multiple interacting systems or a single system that weighs up choice options[5,16–20], deliberation has a central role in intertemporal decision-making that must be elucidated[13,21–23].

In this Perspective, our primary contention is that the cognitive and neural mechanisms that allow people to think about the future (prospection) and about their own thinking (metacognition) are integral to deliberation and that together these capacities produce effects that are responsible for a range of decision-making idiosyncrasies. For instance, the fact that people can anticipate the costs of waiting for a delayed reward means that deliberation can result in seemingly paradoxical 'farsighted impulsivity' and that therefore deliberation does not equate to patience as it is commonly defined[24–26]. We begin by introducing the elements of deliberation and explaining how they interlink, before turning to a range of illustrative choice phenomena. A great deal of research has implicated ingredients of deliberation in the flexibility of human intertemporal choice, such as general cognitive effort[27,28], reflection[29] and working memory capacity[30,31], and it is by building on that background that we develop an account of what deliberation entails and what role it plays in intertemporal choice.

Prospection and metacognition are central to deliberation

Duckworth and colleagues[32,33] theorize that self-control strategies require prospection and metacognition, and they have shown how the development of these abilities in childhood underpins various self-control strategies for overcoming temptations. This idea has roots in views of self-control as a series of interactions between different versions of the self over time[20,34–38]. Here we apply the insight to deliberation in intertemporal choice more broadly. We explain how the abilities of prospection and metacognition are fundamental when people deliberate over intertemporal trade-offs and how the interaction of these two abilities is not additive. The interaction results in qualitatively distinct effects from those produced by either process alone, with consequences for a range of phenomena in intertemporal decision-making.

Prospection involves the representation and evaluation of possible futures. Research into the psychology[39–41], evolution[42,43] and cognitive neuroscience[44–46] of thinking about the future has grown rapidly over the past decades, and it has become increasingly clear that the ability comprises a broad range of phenomena with many constituent elements. Much of the work has focussed on episodic future thinking, which can be defined as the capacity to imagine or simulate events that might occur in one's personal future. Numerous lines of evidence have indicated that episodic memory abilities contribute importantly to the capacity for episodic future thinking[42,45,46]. For instance, neuroimaging research has revealed a close correspondence in neural activity when people remember specific personal memories and imagine possible future events, which led Schacter et al.[47] to describe this shared neural system as a core network involved in simulating both past and future experiences. Box 2 presents more detail and expands on the insights from neuroscience relevant to other sections of this Perspective.

It has become clear from neuroimaging studies and from behavioural and cognitive research that the mechanisms of episodic simulation share close links to those of emotion and valuation[41,48–50].

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Box 1 | Glossary

Cognitive offloading: the use of physical action to alter the information processing demands of a task so as to reduce cognitive demand.

Core network: a network of brain regions that show increased activity both when people remember past experiences and when they imagine future experiences.

Delay discounting: the decline in the subjective value of an outcome with delay to its receipt.

Deliberation: the process by which a decision-maker considers their options, involving representing the options and outcomes, as well as evaluating them. We argue that the higher-order capacities for prospection and metacognition are integral to deliberation.

Dynamic inconsistency: a decision-maker holds dynamically inconsistent preferences when their preferences change or reverse as choice options come closer in time.

Episodic future thinking: the capacity to imagine or simulate experiences that might occur in one's personal future.

Higher-order desire: a desire about a desire, such as when one wants a doughnut, but wants to want a salad instead.

Intertemporal choices: choices with consequences that play out over time, often involving trade-offs between sooner and later outcomes.

Magnitude effect: people tend to discount future rewards less steeply when the values of all choice options are greater, all else being equal.

Metacognition: cognition about cognition; the capacity to monitor, evaluate and control one's own cognitive processes.

Model-based control: in reinforcement learning, model-based control refers to behaviour driven by an agent's internal causal model of the environment. It is contrasted with model-free control, a comparatively less accurate but less effortful strategy in which actions are based on previous stimulus–response reinforcement.

Precommitment: the establishment of restraints over one's own future choice options, usually to lock in a preference for a larger, later reward.

Preference reversal: when an originally stated preference switches as the decision-maker moves closer in time to the choice options.

Prospection: the capacity to mentally represent the future. This is an umbrella term that refers to many forms of future-oriented cognition; episodic future thinking is one form.

Sign effect: people tend to discount the impact of delayed positive events more steeply than they discount the impact of delayed negative events.

Episodic future thinking is therefore a plausible candidate contributor to affective forecasting[41], motivation in goal pursuit[51] and the explicit evaluation of choice outcomes; indeed, the prospection network is often incorporated into general systems models of intertemporal decision-making[6,52,53]. Note, nonetheless, that patients with hippocampal amnesia (who exhibit deficits in episodic memory and, in some cases, episodic future thinking) may make intertemporal choices similarly to healthy controls[54]; this has led to views emphasising the flexibility episodic future thinking affords rather than its necessity for intertemporal choice per se[25,55,56]. A parallel body of research into reinforcement learning has begun to elucidate the processes of model-based control[57]. In contrast to model-free control, which involves habitual responses based on the repetition of stimulus–response pairings, model-based control enables flexible goal-directed planning and is a plausible computational substrate of goal-directed cognition broadly and episodic future thinking in particular[58,59].

Metacognition enables the evaluation and control of prospection. The capacity to represent the relation between a representation and reality is known as meta-representation[60]. This ability is foundational for appreciating that other people may hold false beliefs (theory of mind) and for thinking about alternative ways the past could have unfolded (counterfactual reasoning)[61,62]. Meta-representation also allows for the monitoring and control of one's own cognition—metacognition—for example, in taking stock of one's own memory strengths and weaknesses and compensating for them[63,64]. Recent perspectives from artificial intelligence and computational neuroscience have emphasised the utility of meta-level systems[65–68]. These systems are effective because they can regulate the execution of lower-level processes, for example by determining the value of dedicating computational resources towards solving particular problems over others[36,69].

The critical role of meta-representation in prospection has long been noted[62,70]. As Redshaw and Suddendorf[71–73] have argued, meta-representation allows an individual to evaluate their own prospective cognition (metaforesight), and this therefore produces (i) the insight that one could be wrong about one's beliefs, predictions or reasoning about the future[71]; (ii) the awareness that the future has multiple possible paths that are not just probabilistically different, but mutually exclusive[72]; and (iii) the ability to reflect on what the strengths and weaknesses of one's other cognitive abilities may be in the future[73]. In turn, alternative representations of the future can be evaluated and appraised, for example in terms of their likelihood, plausibility or concordance with one's goals[51,74,75] (Fig. 1c). Jing et al. report that an episodic specificity induction, a procedure that enhances the retrieval of episodic details, boosts the number of alternative possible futures that people imagined during problem-solving[76]. This increase had consequences for the perceived plausibility of the different outcomes, suggesting that the mechanisms of episodic simulation are tightly linked with those responsible for the metacognitive evaluation of those simulations.

Understanding how prospection and metacognition interact in deliberation sheds light on intertemporal choice phenomena

Scholars attempting to make sense of human decision-making have long grappled with the malleability[77], inconsistencies[3], anomalies[78] and apparent paradoxes[50] of real human choices and have noted how these quirks lead to frequent deviations from normative economic rationality[79], as well as away from decision-makers' own best interests[80]. A fuller understanding of the mechanisms underlying deliberation stands to bring many such intertemporal choice phenomena together under a common explanatory framework and leads to a number of explicit predictions and experimental avenues.

Box 2 | Insights from neuroscience

Identifying a core network: The core network of brain activity that supports remembering the past and imagining the future, which closely overlaps with the default-mode network[163], includes regions of the medial temporal lobe, medial prefrontal cortex, posterior cingulate and retrosplenial cortices, as well as regions of the lateral temporal and parietal cortices (see Benoit & Schacter for a recent functional MRI meta analysis[164]).

Mechanisms of precommitment: Recent work on the neural mechanisms of precommitment has implicated the frontopolar cortex[165,166], which has also been associated with the core network introduced above (more so in simulating the future than remembering the past)[167], as well as with prospective valuation, counterfactual thinking and metacognitive control[168–171]. These findings lend suggestive support to the conjecture that precommitment draws upon an interaction of metacognition and prospection instantiated in higher-order executive brain systems[171].

Evaluating imagined futures: Research has consistently linked regions of the core network, especially midline prefrontal regions such as the ventromedial prefrontal cortex (vmPFC), to the integration of value into simulations[49,172]. The vmPFC also appears to play a role in the value of simulated waiting periods: in one recent study, Iigaya and colleagues[173] show that core network regions, especially the vmPFC and hippocampus, are central to the pleasure of anticipation via functional coupling with regions of the dopaminergic midbrain. The authors suggest that signals from the dopaminergic system are projected to the hippocampus and that this amplifies the vivid imagination (and affective quality) of anticipation[173]. Other neuroimaging work connects delay discounting to the role of vmPFC in mental simulation. This includes findings that brain activity in vmPFC during future thinking directly predicts delay discounting[174] and that increased vmPFC activity while participants imagine consuming rewards correlates with shallower discounting[175]. Among the first episodic cuing effect studies, the core network was directly implicated with functional MRI. Benoit et al.[176] showed that coupling of the rostromedial prefrontal cortex and hippocampus was associated with the cue-driven reduction of delay discounting (for similar results implicating coupling of frontal regions and medial temporal lobe regions, see also refs. [177–179]).

Interaction of control and prospection in the magnitude effect: Ballard et al.[160] report greater activity in prefrontal executive control network regions when people made difficult higher-magnitude intertemporal choices. A subsequent repetitive transcranial magnetic stimulation study showed that disrupting activity in the dlPFC reduced the magnitude effect, thereby providing causal evidence for the dependency of the effect on prefrontal executive control regions. In a recent neuroimaging meta-analysis[164], the dorsolateral prefrontal cortex was also shown to be part of the core network and more active during episodic future simulation than episodic memory. The dorsolateral prefrontal cortex is thus a node both of the brain network involved in simulation and of the frontoparietal control network, with all of the above findings implicating it in controlled deliberation over choice alternatives.

Modelling evidence accumulation in deliberation: People take longer to choose between options that are more similar in subjective value, presumably because they deliberate more about such choices[15,180]. The reason that deliberation takes time could be because it involves a sequential sampling from memory (including via retrieval processes that support prospection) to provide evidence about choice options[180]. Recent approaches to modelling value-based decision-making as sequential sampling have revealed new insights about the neural mechanisms of deliberation[15] and may prove a fruitful testing ground for hypotheses about intertemporal choice[85,181–183], including those presented in this paper. For instance, do metacognitive processes play a role in controlling sequential sampling from memory (and thus prospection), such as by determining where the termination criterion should be set (i.e., via an assessment of whether it is worth one's time and effort to imagine any more alternative possible futures)?

Decision-makers deliberate about—and compensate for—anticipated changes of mind. People often express preferences for the future that are different from their preferences in the present[4,81,82]. A smoker intends to quit, but only starting next week; a dieter intends to stop eating carbs, but only in the New Year. The concavity of the delay discounting curves that have been used to represent the loss in subjective value of a reward with increasing time to its receipt captures this dynamic inconsistency[3,50] (Fig. 1a,d). Hyperbolic discounting functions are one modelling approach to intertemporal preferences. These models describe higher discounting rates at shorter delays to an outcome and lower discounting rates at greater delays to an outcome, while a single parameter value, k, captures discounting steepness[34,83] (note that there are alternatives, such as quasi-hyperbolic models, heuristic models and attribute-based models[10,84–87]). In intertemporal choice studies, participants can violate normative economic rationality (which typically models delay discounting as a time-consistent exponential decay of value) by declaring, for instance, that they would prefer $40 today over $50 in a month, but that they would also prefer $50 in 12 months over $40 in 11 months. Here how far away the decision-maker is from the options influences their preference, holding constant the delay between the outcomes and the magnitude of the rewards. Preference reversals occur when an originally stated preference for a larger, later reward relative to a smaller, sooner one switches as the decision-maker moves closer in time to the two options. In Fig. 1b, this is when the two hyperbolic discounting curves cross. Hence the dieter, come New Year's Day, shifts back to a preference for eating doughnuts (the diet can always start tomorrow).

Prospection allows decision-makers to anticipate their own preference reversals (Fig. 1c). Perhaps unlike any other animals (see the Bischof-Köhler hypothesis[42,88,89]), humans readily, though sometimes with difficulty, recognize that they may be angrier, hungrier or craving more intensely in the future than they are now[41,90] and, therefore, that their intertemporal preferences may change[91]. This recognition entails the interaction of metacognition and prospection because it requires a decision-maker to evaluate the characteristics of a future simulation itself or of their other cognitive processes in a future simulation[73,92] (for instance, "how likely am I to want the doughnuts after a long day at work"). The recursive interplay of metacognition and prospection is thereby also expressed in higher-order desires: people frequently want to want other things[93], such as wanting to want salad instead of doughnuts. Collectively these cognitive processes may be directly responsible for the puzzling phenomenon of precommitment[3,4,32,37,86,94], the establishment of restraints over future options. For example, the dieter may decide to throw away all the

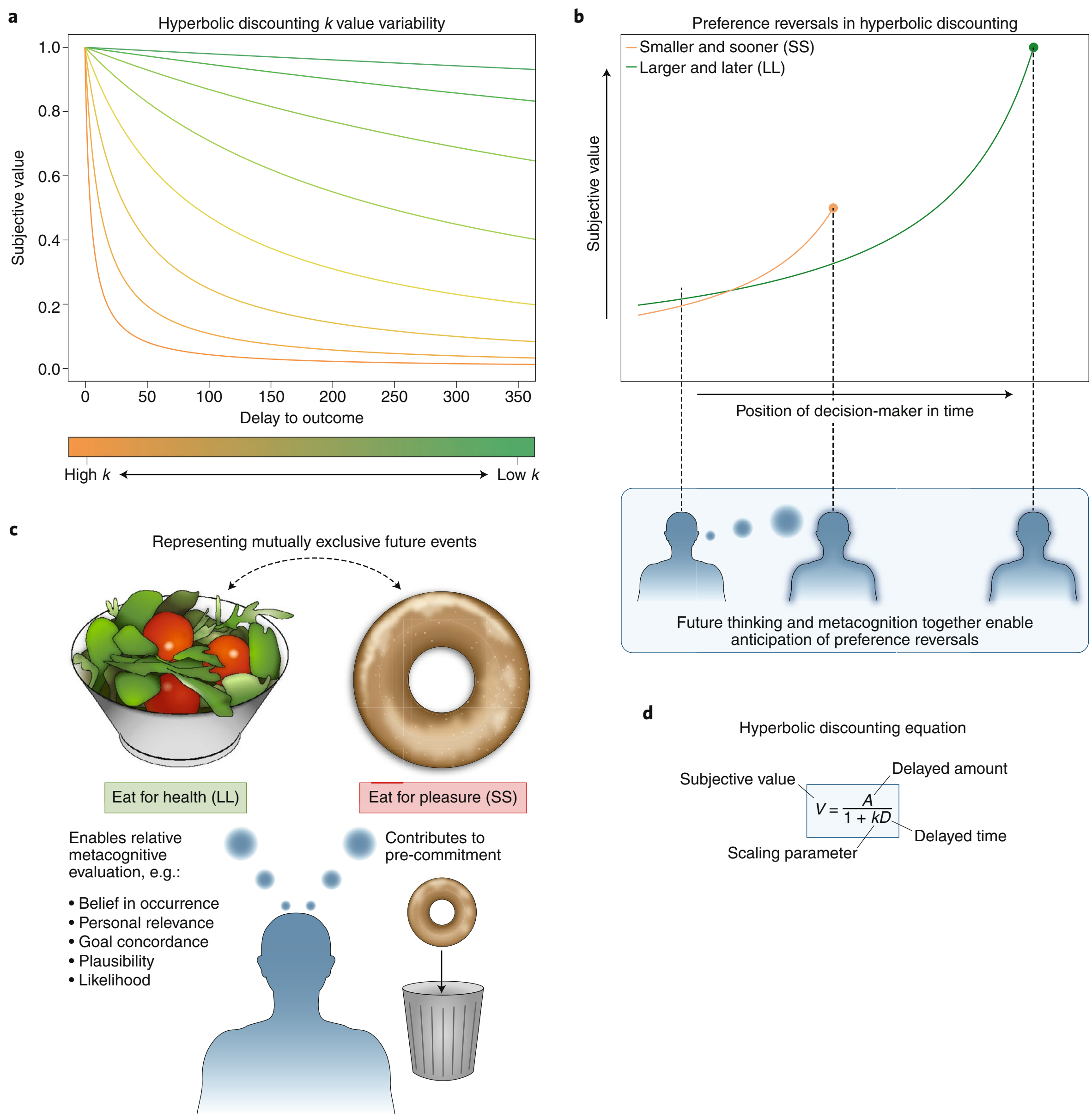

Fig. 1 | Deliberating over anticipated changes of mind. **a**, A popular hyperbolic model describing delay discounting; higher *k* values represent steeper discounting of value with time, while lower *k* values represent shallower discounting. **b**, A preference for a larger, later reward relative to a smaller, sooner one can change when both move closer in time. The interaction of metacognition and prospection enables people to anticipate these preference reversals. **c**, This interaction also underlies the insight that the future contains mutually exclusive possibilities, such as adhering to a diet or not. People evaluate these alternative futures on dimensions such as plausibility or likelihood, which helps explain precommitment (throwing away one's doughnuts). **d**, In the hyperbolic discounting model, *k* is a free scaling parameter that accentuates or dampens the effect of delay on value.

doughnuts in December to pre-empt snacking once a currently undesired preference-reversal occurs.

It has been questioned whether initiating a pre-commitment strategy necessarily requires the simulation of a future preference reversal[95,96], and this is a key target for future research. To better elucidate the psychological and neural mechanisms, it may be useful to integrate external pre-commitment into a recently proposed metacognitive model of cognitive offloading, the use of physical action to alter the information processing demands of a task[97–100]. Such a view would treat compensating for anticipated preference reversals via external pre-commitment as analogous to, for example, compensating for anticipated memory failures by setting reminders[97,101,102]. In both cases, a decision-maker has a prospective intention that they wish to pursue (e.g., not to eat the doughnuts; not to forget to water the plants). In both cases, the interaction of metacognition and prospection is required to assess the relative costs and benefits of external versus internal strategies (see also ref. [103]). Future research into the correspondence between cognitive offloading and pre-commitment may therefore elucidate the higher-order processes that facilitate the pursuit of intentions. For instance, perhaps compensating for anticipated changes of mind in both cases initially requires effortful and self-reflective deliberation but can then become automatized.

Metacognition means prospection is recursive, which produces effects of anticipated anticipation on choice. Economists have long noted that decision-makers derive utility (or dis-utility) not only from outcomes during intertemporal choice, but also from the delay to those outcomes[79]. The emotional experiences of dread and savouring are representative cases, first expounded in detail by Loewenstein[78,104]; they reflect the negative and positive value, respectively, of anticipation during delay. In cognitive and clinical psychology, there has meanwhile been much research into the interplay of emotion and episodic simulation[105–107], and this has underscored that episodic future thinking can readily evoke emotion as if an emotional event were really occurring[108]. Anticipatory emotions like dread and savouring are therefore likely to rely upon episodic processes[104,105,109,110]; though this conjecture has remained largely untested. Box 2 details an initial promising neuroimaging and modelling approach that supports the conjecture.

Not only do people derive utility from simulating emotional future events, they also adjust their decisions according to the value of the experience they expect to have during the delay period[111]. This leads decision-makers to postpone a vacation or save a bottle of wine so they can enjoy the anticipation, in violation of expectations from hyperbolic discounting models[104,112]. Similarly, when given the choice between suffering different amounts of pain at different times in the future, people will sometimes opt to 'get it over with'[113], which reflects the mental accounting of anticipated dread, rather than just dread itself[114,115]. This phenomenon may account for the fact that the value (impact) of negative future outcomes tends to be discounted less steeply than positive outcomes (the sign effect), given that the anticipated negativity of dread may contribute more to the impact of delayed negative outcomes than anticipated savouring does to positive ones[112,116].

Anticipating dread and changing decisions accordingly requires a decision-maker to anticipate what they will anticipate if they make a certain choice (Fig. 2a). Anticipated dread is thus also a recursive operation, in that the underlying process of anticipation calls upon itself[117]. This raises a largely unexplored question about the role of episodic simulation in deeper levels of recursive thinking during intertemporal choice, such as in anticipated regret[118,119]. Anticipated regret has three levels of recursive embedding because regret itself is a two-level counterfactual (i.e., it requires appreciating that 'a different past choice would have led to a different future'[72,120]), and it is associated with activity in core network regions (perhaps implying episodic simulation[121]). The perspective outlined here predicts that the sign effect would be absent in people incapable of episodic simulation of the delay period, such as certain individuals with hippocampal amnesia (even if they discount delayed rewards normally[54,122,123]).

Cuing people to simulate future events can reduce delay discounting. A number of studies have directly cued participants to simulate future events while they make intertemporal decisions, an episodic cuing procedure that produces robust reductions in delay discounting (e.g., Fig. 2c). This effect has been directly and conceptually replicated a number of times (see Bulley et al.[25] and Schacter et al.[123] for reviews, and see Rung & Madden[124] for a recent meta-analysis). Studies on episodic cuing of discounting emerged after Boyer[125] suggested that a major evolutionary function of imagining the future is the curtailing of delay discounting. In this view, episodic simulation is proposed to act as a motivational brake on short-term preferences. A computational model of the role of search processes in intertemporal choice accounts for the episodic cuing effect by suggesting that it makes future choice outcomes easier to locate and evaluate during deliberation[21], though the precise mechanisms of the effect remain opaque (see Box 2 for a discussion of the neural mechanisms). There is also some variability in the size of the cuing effect between studies[124], and there are ongoing debates about what simulated content is responsible for the effect (including regarding whether memory retrieval can also reduce discounting[126–128]). For instance, various studies have shown the episodic cuing effect by having participants imagine relatively banal, everyday events, while others have taken pains to have participants simulate goal-relevant events where the effects may be stronger because of the close relationship between episodic future thinking and goal pursuit[51,129].

There are also conflicting results about the role of valence in the episodic cuing effect. Two studies initially showed elevated delay discounting when participants were cued to imagine negative future events relative to control imagination[130,131], but in two subsequent studies, both negative and positive episodic future cuing resulted in reduced delay discounting relative to control imagination[126,132]. Metacognitive evaluations may prove informative in determining when different event simulations lead to different patterns of intertemporal decision-making. One candidate pertains to the controllability of the imagined events. For instance, it is possible that imagining a negative event as within one's control might spur preparatory motivation, while imagining a negative event that is out of one's control might encourage steeper delay discounting[7,133]. Given the preceding discussion of the role of savouring and dread during discounting, one explanation for the positive episodic cuing effect is that episodic simulation causes people to reflect on and anticipate the pleasure derived from waiting for rewards (regardless of whether imagined events are negative or positive). One interesting prediction is therefore that episodic cuing during discounting of negative outcomes would, at least for a substantial portion of participants, accentuate 'get it over with' choices by bolstering the weight of anticipated dread.

Deliberation does not equate to patience. Contrary to its frequently assumed role, greater deliberation does not necessarily lead to the pursuit of larger, later rewards[25,134,135]. For instance, people sometimes regret missing out on pleasurable experiences in pursuit of a later goal[136]. Foreseeing this regret, a consumer may intentionally splurge on indulgences like an expensive dinner[26,137], and this would be incorrectly called short-sighted by those failing to understand the causal metacognitive and prospective deliberation involved[24]. In a similar vein, people may intentionally choose a smaller, sooner reward if they do not trust that they will obtain a larger, later one[138], a fact that helps explain the steeper discounting observed amongst people living in poverty[7,133,139] and perhaps also the robust individual and cross-national associations between lower life expectancy and steeper delay discounting[140–142]. Even young children will modify their intertemporal choices based on their expectations of environmental reliability. In one study, when an experimenter broke a promise before conducting a version of the marshmallow test[143], the average waiting time among 3- to 5-year-olds fell from 12 to 3 minutes[144].

In addition to uncertainty about the likelihood of a delayed payoff, uncertainty about the length of delay to receipt may similarly drive choices for sooner, smaller rewards given certain prior beliefs[145–147]. For instance, in some cases the longer one has waited for an outcome, the longer one might expect to wait (such as when waiting in a queue). Recent work shows that people prioritize immediate relative to delayed rewards in line with such predictions about the delay to a payoff[147]. Aside from representing such uncertainty as intrinsic to various future events, representing future scenarios as uncertain may be performed metacognitively, for instance when it involves assessing whether one's simulation of the future is plausible, accurate or will actually occur, or when explicitly comparing and appraising mutually exclusive possible future alternatives[74], such as imagining both waiting only a short time and waiting a long time for an outcome.

In the clinical domain (see also Box 3), people diagnosed with anorexia nervosa in an acutely ill underweight state exhibit reduced (shallower) delay discounting relative to controls, contrary to the vast majority of other patient groups, who exhibit steeper discounting[5,148]. Weight recovery in remitted anorexia leads to an increased prioritization of sooner, smaller rewards[149,150]. This increase may be

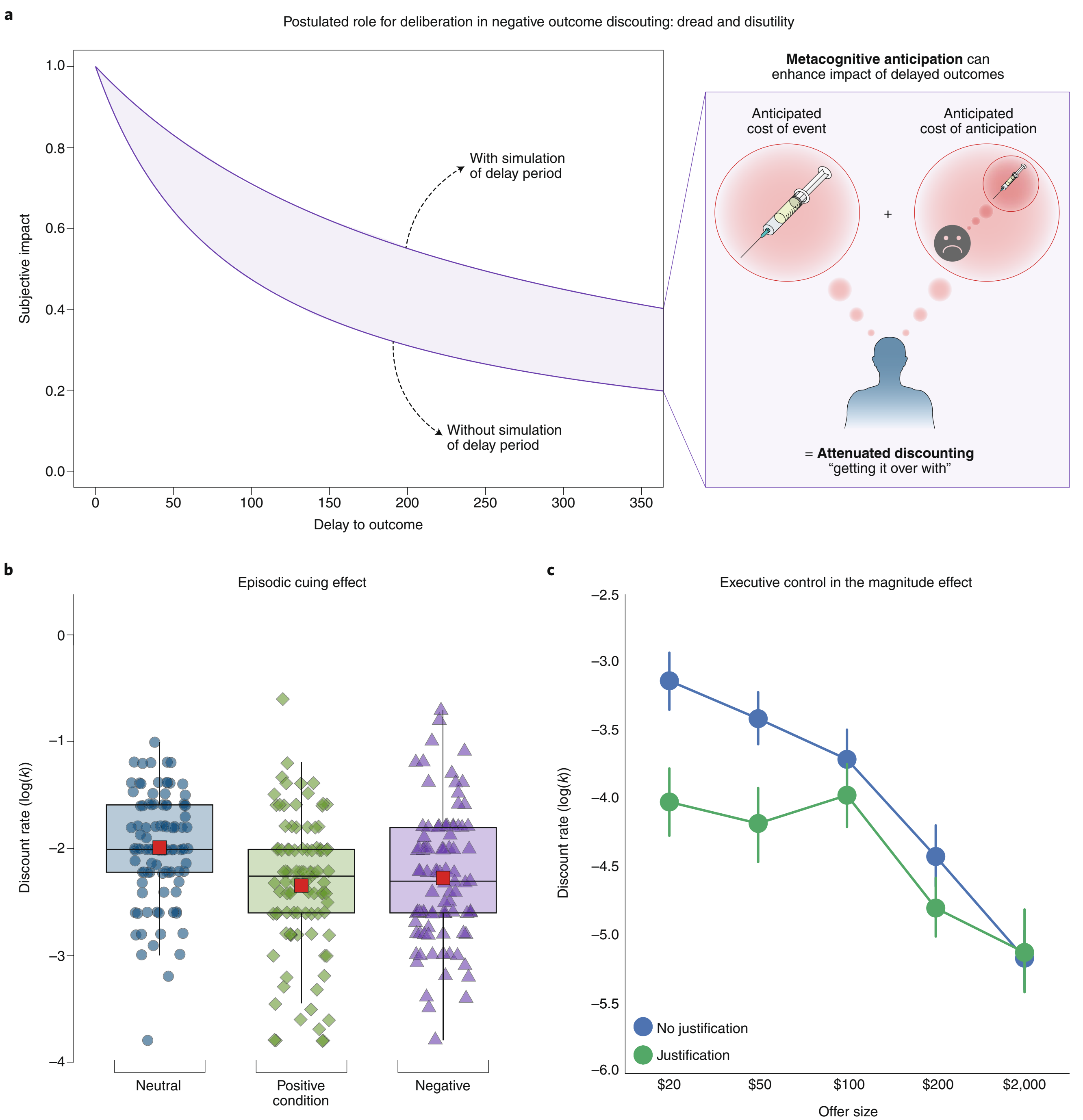

Fig. 2 | Deliberation in intertemporal choice phenomena. a, Schematic of postulated role for metacognition and prospection in delay discounting of negative outcomes. With increasing time, the subjective impact of a negative outcome decreases: people tend to prefer postponing negative events. However, with the capacity to anticipate the dread leading to a negative outcome, people sometimes opt to have unavoidable negative experiences sooner rather than later. This would correspond to a reduced discounting of the impact of a negative outcome. **b**, Cuing participants to imagine either positive or negative future events reduces delay discounting relative to neutral control mental imagery ($n = 297$); data from Bulley et al[126]. **c**, Asking participants to justify their choices increases cognitive control, and this reduces the magnitude effect by selectively increasing patience for smaller rewards; large rewards are presumed to already elicit greater control ($n = 1{,}382$). Reproduced with permission from ref. [160], Sage Publications.

precisely because treatment re-establishes cognitive resources that enable greater deliberation and executive control and thus the overcoming of pathological patience[150,151]. This case, as with the other examples presented in this section, makes it clear that deliberation and patience cannot be equated. Patterns of 'farsighted impulsivity' may explain recent null or opposite-to-predicted results when researchers have explored links between delay discounting and model-based planning[152] (though see ref. [27]), visualisation abilities[153] or individual differences in episodic future thinking[154]. If greater deliberation can lead to either greater patience or greater impulsivity, the two constructs will not always correlate. Instead, a nuanced approach focussing on the constituent processes of both deliberation and intertemporal choice may be revealing. In one recent study, even though delay discounting and model-based control did

Box 3 | Promising avenues for clinical intervention

Steeper delay discounting has been observed in a variety of behavioural health issues and psychopathologies, leading to calls for it to be considered a trans-disease process[5]. Delay discounting is also therefore a primary target for clinical intervention[6]. The potential clinically significant role of individual differences in prospection and metacognition in deliberation during intertemporal choice has received less attention (though see refs. [184–186]), but there are a number of promising avenues for future research.

If deliberation is reduced, one possibility is to find alternative, compensatory strategies that do not put demands on it. For example, establishing self or other-imposed commitments, rules, habits or principles that may require only an initial deliberative commitment and then a less-deliberative execution could be effective, but may also impose other cognitive demands. For a comprehensive recent taxonomy of such strategies and their relative merits, see Duckworth et al.[187]. This approach may be particularly useful in clinical settings where deliberation or executive control has deteriorated. For instance, rigidity and reduced cognitive flexibility (including impairments in episodic future thinking) manifest in a range of dementia subtypes, alongside maladaptive shifts in delay discounting (e.g., behavioural variant frontotemporal dementia[188,189]), and so compensatory strategies here could be particularly useful[186]. A parallel can be again evoked with cognitive offloading, which is commonly adopted in the context of dementia or brain injury when memory begins to fail (reminders, lists, online calendars, etc.)[190–192]. Studying patient populations who have selective impairments to certain kinds of prospection may also prove informative for basic science, in delineating the respective role of episodic versus semantic processing in the various effects of prospection discussed in this paper[46,55].

It may be possible to selectively boost deliberation, instead of compensating for its loss. Promising results discussed in this paper include the attenuation of the magnitude effect, the episodic cuing effect (particularly in clinical contexts like obesity or substance use disorder treatment[193–195]) and a range of other behavioural interventions such as implementation intentions[196]. Recent results also suggest that metacognition can be directly improved with training[197]. Together, these studies suggest that intervening at the level of specific deliberative processes may prove fruitful.

not correlate, the amount of time spent deliberating over intertemporal choices correlated with measures of model-based multistep planning[155].

Framing and magnitude effects may result from meta-control of deliberation. Intertemporal decisions depend on many contextual, situational and framing variables[77]. We highlight two here to illustrate how understanding the mechanisms at play during deliberation can be informative: explicit zero framing and the magnitude effect. Laboratory intertemporal choice questions typically contain no reference to the foregone alternatives implicit to each choice option. For example, the question "would you prefer $40 today or $55 in 62 days?" contains implicit zero values that can be made explicit as follows: "would you prefer $40 today and $0 in 62 days or $55 in 62 days and $0 today?" This explicit zero framing has been shown to reliably reduce delay discounting[156,157]. One reason is that participants appear to be drawn selectively to consider the opportunity cost of choosing the smaller, sooner reward (the foregone opportunity to gain more money later)[158].

Mentally accounting for delayed opportunity costs rests on the insight that there are branching, mutually exclusive possible versions of the future and that particular choices close off particular branches[72] (Fig. 1c). A recent study directly tested the possibility that explicit zero framing would enhance the simulation of choice alternatives. Jenkins and Hsu[159] report that explicit zero framing (i) increased self-reported and other-rated imagination of intertemporal choice outcomes; (ii) boosted imagination of larger, later rewards more than smaller, sooner ones; and (iii) enhanced activation in regions of the core network involved in episodic future thinking (relative to regions involved in executing willpower). The increased imagination of choice alternatives, and in particular imagining larger, later reward outcomes, predicted the framing-induced shift in willingness to wait.

People reliably discount future rewards less steeply when the options are of larger magnitude. Ballard et al.[160] propose that this magnitude effect occurs because people invest greater cognitive control (and hence probably more deliberation) into choices deemed more important. In support of this idea, having participants justify their choices, which requires considering the reasons behind decisions, attenuated the magnitude effect. The justification-manipulation selectively reduced delay discounting for smaller magnitude options, while larger magnitude options—which are presumed to already elicit high control—were not affected (Fig. 2c; see Box 2 for additional supportive neuroscience findings).

If larger magnitude choices engender greater control processes, then the magnitude effect may be a manifestation of the interaction between metacognition and prospection. Meta-control systems are responsible for allocating levels of effort[69], and the same may be true of deliberation about the future[67]. In a recent model, Gershman and Bhui[161] show that the magnitude effect could emerge from meta-control of prospective simulation. Simulating the future is a noisy process[162], but this noisiness can be attenuated by allocating greater (costly) cognitive control. When the stakes of a choice are higher, the meta-control system should be more willing to accept this cost and boost the precision of episodic simulations, thereby reducing delay discounting for higher magnitude relative to lower magnitude outcomes[161]. Note, however, that at least one individual with hippocampal amnesia (with deficits in episodic future thinking) showed the magnitude effect, raising questions about the relative contributions of episodic and semantic prospection in the aforementioned deliberative process[54]. The potential role of metacognitive control over deliberation in the magnitude effect suggests a striking possibility: by primarily studying relatively small, mostly monetary choices, we may have greatly underestimated the role of deliberation when people make intertemporal choices, which in the real world frequently concern matters of much graver importance: what work to pursue, who to partner with, how to provide for one's descendants.

Conclusion

While it has been well documented that decision-making commonly results from the operation of rules, intuitions and habits, in this Perspective we have emphasized the other side of the coin: people also deliberate considerably about their intertemporal decisions. Recent research into the psychological and neural mechanisms of deliberation stands to provide a deeper understanding of how humans make intertemporal choices, with implications for a range of recognised decision-making phenomena. We have focused on the role of metacognition and prospection during deliberation to show how together these processes allow humans a sophisticated degree of mental accounting for the later consequences of their decisions. We have only attempted to illustrate the promise of this direction, by pointing to a range of work from cognitive neuroscience, behavioural economics, clinical neuropsychology and other areas of the behavioural sciences that have contributed important insights.

We have proposed a number of specific predictions about intertemporal choice generated by the perspective that the interaction of metacognition and prospection underpins deliberation. However, the burgeoning research in this area stands to make a great deal of further progress by integrating new interdisciplinary findings in pursuit of a cohesive understanding of how humans think through trade-offs with the future.

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