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**The role of prospective cognition in human decision-making: proximate and ultimate perspectives**

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**Abstract**

The future abounds with potential opportunities and threats. While we cannot know for certain what most of this future holds, a fundamental feature of the human mind is the ability to disengage from the here-and-now to anticipate, plan, and prepare. Having the future in mind enables people to modify their decision-making in diverse and flexible ways in line with the consequences of their choices. In this thesis, I explore the role of prospective cognition in the intertemporal trade-offs we make between immediate and delayed outcomes, the anxieties we feel, and the steps we take now to compensate for our anticipated limitations.

In chapter one, I survey the scientific history of prospective cognition in psychology and related disciplines, and outline the evolutionary importance of foresight and decision-making. In chapter two, I review the role of prospective cognition in intertemporal decision-making and present a mechanistic model that outlines how the prediction of likelihoods and emotions enables people to make more flexible intertemporal trade-offs. Chapter three presents the results of an experiment in which participants were cued to imagine positive future events while they made intertemporal choices. Imagining the future reduced the rate at which people discounted the value of future monetary rewards. It also marginally (but not consistently) reduced their hypothetical alcohol demand patterns, suggesting the effects of prospective cognition on ‘impulsivity’ may be limited to particular domains.

I survey the human capacity and tendency to imagine future threats in chapter four, wherein I present a taxonomy of threat-related cognition. This taxonomy connects disparate approaches to anxiety and mental time travel – our capacity to remember personal past events and imagine future ones. I outline how foresight empowers people to manage anticipated threats, but also how these same processes lie at the heart of contemporary anxiety disorders. In chapter five, I present results from a cross-country analysis into the role of threat in intertemporal choice. Across countries, a lower life expectancy was associated with both a smaller percentage of people willing to wait for a larger but delayed reward, as well as women having their first child at a younger age. These results, which hold after controlling for global region and gross-domestic product per capita, dovetail with findings at the individual level to suggest environmental threats can be an important predictor of intertemporal decision-making. To directly address the causal influence of imagining future threats on decision-making, in chapter six I present the results of a large-scale experiment in which participants were cued to imagine future threats or positive events while making intertemporal choices and risk-taking decisions.

Being cued to imagine either type of future scenario led participants to discount the value of future rewards significantly less than engaging in emotionally neutral control imagery, but cued foresight had no effect on risk-taking. Thus, while these results again replicate previous findings that cued foresight can reduce delay discounting, they indicate that this effect is not dependent on emotional valence and suggest further boundaries on its generalizability to other decision-making domains.

In chapter seven, I survey some of the most critical functions of the prospective mind. In each case, I argue that human metacognition – our ability to think about our thinking – bolsters these capacities. People can reflect on and compensate for the natural limits of their foresight. For example, we make contingency plans because we appreciate that initial predictions may turn out to be wrong. I suggest that the processes involved in monitoring, controlling, and augmenting prospective cognition represent an important and understudied parallel of *metamemory* that should be called *metaforesight*. Chapter eight is an experiment into the developmental origins of metaforesight: how do children acquire the ability to compensate for their future failures? I show that even children as young as four years of age are capable of rapidly learning to set themselves reminders to compensate for future memory limits. However, the selective deployment of this behaviour congruent with cognitive demand increased gradually throughout childhood – in line with a body of literature on the development of metacognitive control.

Chapter nine is a general discussion, wherein I suggest avenues for future research into the mechanisms and development of prospection in decision-making, as well as the clinical relevance of the findings in this thesis. Finally, I reflect more broadly on the evolutionary legacy of prospective cognition in human decision-making and explore ways it could be leveraged to better steer us forwards. Overall, this thesis underscores why making decisions with the future in mind is such a powerful element of the human psychological toolkit.

**Declaration by author**

This thesis is composed of my original work, and contains no material previously published or written by another person except where due reference has been made in the text. I have clearly stated the contribution by others to jointly-authored works that I have included in my thesis.

I have clearly stated the contribution of others to my thesis as a whole, including statistical assistance, survey design, data analysis, significant technical procedures, professional editorial advice, financial support and any other original research work used or reported in my thesis. The content of my thesis is the result of work I have carried out since the commencement of my higher degree by research candidature and does not include a substantial part of work that has been submitted to qualify for the award of any other degree or diploma in any university or other tertiary institution. I have clearly stated which parts of my thesis, if any, have been submitted to qualify for another award.

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## Publications included in this thesis

**Peer-reviewed papers:**

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## Contributions by others to the thesis

My primary supervisor Thomas Suddendorf provided important feedback on full drafts of this thesis. The contribution of co-authors to specific chapters is specified on the page preceding each chapter.

## Statement of parts of the thesis submitted to qualify for the award of another degree

No works submitted towards another degree have been included in this thesis.

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## List of abbreviations

**vmPFC:** Ventro-medial Prefrontal Cortex

**mrPFC:** Medial-rostral Prefrontal Cortex

**ACC:** Anterior Cingulate Cortex

**VS:** Ventral Striatum

**ICT:** Intertemporal Choice Task

**APT:** Alcohol Purchase Task

**AUDIT:** Alcohol Use Disorders Identification Test

**PTSD:** Post-Traumatic Stress Disorder

**GDP-PC:** Gross Domestic Product Per Capita

**INTRA:** International Test on Risk Attitudes

**AIC:** Akaike Information Criterion

**OSF:** Open Science Framework

**MCQ:** Monetary Choice Questionnaire

**BART:** Balloon Analogue Risk Task

**SRSI:** Strategic Reminder Setting Index

# Chapter One. General introduction

## Preface and details of contribution to authorship:

In this general introduction, I provide a scientific history of prospective cognition in psychology, philosophy, artificial intelligence, neuroscience, and related disciplines. I outline the evolutionary importance of foresight and describe the focus on decision-making in this thesis. I then outline the approach that the thesis will take overall and summarise the main contributions of each of the chapters that follow. I am the sole author of the chapter, with some of the text adapted from a review article (Bulley, 2018).

### 1.1. The centrality of prospection to the human mind

In the year 1901, a group of Greek sponge divers pulled an enigmatic artefact from the Aegean Sea: a lump of wood and metal that would only many decades later be identified as the world's earliest-known analogue computer (Freeth et al., 2006). The device, approximately two thousand years old and called the *Antikythera mechanism,* is of astonishing technological complexity (Marchant, 2006). Analyses of the object in recent decades have revealed that it functioned as a predictive machine. It was used to represent the future of the heavens: the movement of the planets, position of the sun, and the phases of the moon. Once predicted, the operators of this device used the information to prepare for the future: most likely in timing their agricultural and religious activities. Modern computer simulations suggest the device would have successfully predicted even recent eclipses, including the one whose shadow crossed the United States on August 21st, 2017 (Wolfram 2017). The Antikythera mechanism tells us that for thousands of years humans have gone to astonishing lengths to predict and prepare for the future – the result of a fundamental psychological capacity for future-oriented or *prospective* cognition.

*Figure 1.1.* The Antikythera mechanism. Image by Marsyas, CC-BY 2.5.

There is little doubt that prospective cognition in humans has an extensive lineage running back into prehistory. Consider a recently reported set of ground-edged hatchets from Northern Australia (Clarkson et al., 2017). At approximately 65,000 years old, they are the world's oldest-known. The tools were long-lived, and creating their highly polished edges required extensive abrasion with other rocks (Dickson, 1980). They were also continually maintained, reshaped and reworked, with worn or damaged edges repaired so they could be used again when needed in the future (Hiscock, O'Connor, Balme, & Maloney, 2016). Further back, perhaps some of the earliest evidence for prospective cognition in any *Homo* species comes in the form of Bifacial hand-axes (Hallos, 2005), the oldest of which may be more than 1.76 million years old (Lepre et al., 2011). The complex production process of bifaces required more advanced planning than earlier tools (Wynn & Coolidge, 2016). Moreover, they appear often to have been built in one location and then transported elsewhere for repeated use (Ambrose, 2010).

An ancient stone tool like the biface might seem to have little in common with the Antikythera mechanism. But both objects can be considered extensions of a mind geared towards the future. Only with behaviours enacted in the present moment, including the creation of powerful tools, can future successes be ensured, and disasters averted: the crops kept alive, the predators warded off. The same logic applies to a great many of the artefacts of humanity that have been fashioned over the eons: walls to stop potential invaders, writing to remember the debtor, seed-banks in case our planet begins to expire. Such artefacts reflect a more general underlying fact: many of the mechanisms of human cognition are fundamentally future-oriented. The rise and growth of this prospective cognition has been a powerful driver of our evolutionary success as a species (Suddendorf and Corballis 2007).

The capacity to imagine the future – and to thereby envisage, anticipate, plan, and prepare – is powerful because of what it does in the present. It enables people to modify their decision-making and behaviour now in line with what they expect might come later. In this thesis, I explore the role of prospective cognition in human decision-making: how, precisely, do people adapt their choices in accordance with what they foresee? What are the evolutionary origins of this adaptive flexibility? And how do the underlying components work together and develop? In this introductory chapter, I present a brief historical sketch to illustrate the interdisciplinary legacy of the study of prospective cognition, before outlining the approach that this thesis will take and summarising the main contributions of each of the chapters that follow.

## 1.2. A brief history of the future in mind

The future-oriented capacities of the human mind have been seriously discussed by thinkers from Seneca (65 AD) to Schopenhauer (1918). The seventeenth-century political philosopher Thomas Hobbes declared that “the opinions men have of the rewards and punishments which are to follow their actions are the causes that make and govern the will to those actions” (1640, p.103) – a sentiment echoed during the formation of psychology as a discipline in William James’ *Principles of Psychology I* (1890). James argues that the fundamental function of the cerebral hemispheres is to simulate “remote objects” and “distant ends” that are not currently available to the senses. “[In] the cerebrum itself the same general distinction obtains, between considerations of the more immediate and considerations of the more remote. In all ages the man whose determinations are swayed by reference to the most distant ends has been held to possess the highest intelligence” (1890, p. 20). In *Principles of Psychology II*, in a chapter dedicated to “the will” James deals at length with deliberation, anticipation, and voluntary action. Thus, as is often the case in psychology, James founded much of the current discussion – and there has been little hiatus in the interim.

Aside from his well-known work on cognitive maps and latent learning (1948), Edward Tolman earlier wrote at length about *purpose* as it related to psychological processing. He defined human thought as “an internal presentation to the organism (on the basis of memory and association) of stimuli not actually present *but which would be present, if some hypothesized action were carried out*” (my emphasis) (Tolman, 1920, p. 230). In his remarkably prescient *The Nature of Explanation* (1943), English philosopher Kenneth Craik paralleled this idea, introducing the concept of “mental models” and discussing their potential function as tools for organising behaviour in the face of upcoming dangers and opportunities.

In the United States, the concept of mental models arose at around the same time as *cybernetics*, a field that bought together control systems theory, information theory, neuroscience, anthropology and psychology to study “*control and communication in the animal and the machine”* – the subtitle of a seminal book by Norbert Wiener (1948). Cyberneticists examined systems that operate as if they have *goals* (The word cybernetic is derived from the Greek κυβερνάω [kubernáō] meaning steersman, governor, pilot, or rudder.) In the 1940s and 1950s, cyberneticists placed a strong emphasis on prediction and feedback in the context of adaptive functioning. Those concepts eventually found a home in artificial intelligence research (Wiener, 1948). A highly fruitful bi-directional relationship between the cognitive sciences and artificial intelligence followed, with search problems, planning, and goal-direction being productive areas of joint interest (reviewed in Russel & Norvig, 2009).

*Plans and the Structure of Behaviour,* published in 1960 by George Miller and colleagues, applied cybernetics to psychology and became a founding text of the cognitive revolution (Miller, Galanter, & Pribram, 1960). Miller et al. argued that complex step-wise planning might emerge through the operation and manipulation of internal mental models. Arguably, then, one of the hallmarks of the cognitive revolution in psychology was the introduction of prospection as expressed in the goal-directed control of behaviour. Around the same time, social psychologist Walter Mischel had begun to investigate the capacity of young children to postpone their immediate gratification in pursuit of delayed rewards (Mischel, 1961), though one should note that the concept of delayed gratification – the capacity to inhibit desires for temptations in pursuit of long-term ends – has parallel roots in sociology and economics (Straus, 1962; Strotz, 1955). In the 1970s, the study of *intertemporal choices* between immediate and delayed rewards, a focus of this thesis, was extended to pigeons (Ainslie, 1974), and later to many other non-human animals (Redshaw & Bulley, 2018; Stevens, 2010).

Prospection, forecasting and goal-directedness were central to much of Daniel Kahneman and Amos Tversky's Nobel-prize winning research during the 1970s (e.g. Kahneman & Tversky, 1977). Around the same time, developmental psychologists were using linguistic analyses of young children's vocabulary to track understanding of the future (Harner, 1975), and cognitive psychologists were beginning to study the mechanisms of prospective memory and delayed intention-setting (Meacham & Singer, 1977). Learning theory was also being placed on a foundation of *expectation* (Rescorla & Wagner, 1972), and neuroscientists had started to consider the role of the frontal lobes in executive functions and planning (Nauta, 1971). Endel Tulving presented a framework for memory (1972) at this time, which became foundational in the study of mental time travel in both temporal directions, soon encompassing "foresight" or "future thinking" as well (Suddendorf & Corballis, 1997; Endel Tulving, 1985a). In the 1980s and 1990s, philosophers offered detailed treatments of intention and planning (e.g. Bratman, 1987). Meanwhile, economists continued to investigate the way prospective emotions guide decision-making (Frank, 1988), and clinical psychologists investigated their influence on affective disorders (A. T. Beck, Emery, & Greenberg, 1985; MacLeod, Tata, Kentish, & Jacobsen, 1997). Studies of patients with frontal lobe damage came to corroborate hypotheses about how the frontal lobe functions in adaptive goal-directed cognition (Damasio, 1994; Ingvar, 1979, 1985).

In 1997, Suddendorf and Corballis presented a seminal treatment of mental time travel, describing in detail its possible subcomponent processes and evolutionary heritage. Working in parallel, other scientists were investigating sensory and behavioural neuroscience, developing arguments supporting the brain-basis of learning by prediction error. Those arguments led to theoretical models that identified prediction as a key aspect of sensory processing and deep learning (e.g. Dayan, Hinton, Neal, & Zemel, 1995). Models like these, grounded in artificial intelligence research, found substantive empirical support in emerging neuroscientific investigations, including those delineating a key role for dopamine in reward prediction (Berridge & Robinson, 1998; Schultz, Dayan, & Montague, 1997). By the 2000s, the invention of neuroimaging led to a series of studies that served to corroborate the notion that memory and foresight should be thought of as two sides of the same coin (Addis, Wong, & Schacter, 2007; e.g. Okuda et al., 2003; Schacter, Addis, & Buckner, 2007, 2008).

Since the turn of the millennium, a thriving research industry has emerged on the back of this rich history. Some major reviews have recently been published (Schacter, Benoit, & Szpunar, 2017; Szpunar & Radvansky, 2015), as well as a number of books and edited volumes (Bar, 2011; Clark, 2015; Macleod, 2017; Michaelian, 2016; Oettingen, Sevincer, & Gollwitzer, 2018; Suddendorf, 2013). I will expand on the precise definition of the fuzzy term *prospection* and detail the related vocabulary later. For the time being, I hope to have demonstrated with this historical sketch (which I cannot hope to have been exhaustive) that the study of the future-directed features of the human mind has a long and deeply interdisciplinary history. In all disciplines, however, it has become clear that the capacity of the human mind to take account of the future gives rise to substantial powers.

### 1.3. Why decision-making?

A central challenge facing all animal life is the acquisition of resources and the allocation of those resources in the pursuit of opportunities and avoidance of threats. As a result of selective pressures acting upon this basic imperative, many animals have evolved to *prefer* some outcomes over others (Damasio, 2009; Dolan, 2002; D. T. Gilbert & Wilson, 2007). The desirability of an event in the world is an indicator of its fitness value: the propensity for that event to foster – or to hamper – reproductive success (Panksepp, 1998). To make a decision, then, is to evaluate options and, based on the relative value of those options, enact a course of behaviour in line with that information (Rangel, Camerer,

& Montague, 2008). When defined in this manner, decision-making is a ubiquitous feature in the lives of humans and other animals (Stevens, 2011).

The machineries of decision-making, have, over evolutionary time, undergone many overhauls and a great deal of fine-tuning. Various sources of information may be employed in the ascription of value, depending in large part on the ecological niche of the species making the decisions (Gigerenzer & Goldstein, 1996). One particularly important source of information is about the *timing* of events. Because the causal arrow of time points in only one direction, the consequences of a decision made in the present play out only after a delay. Sometimes this delay is short, and outcomes are tied closely to their antecedent causes. Often, however, this delay is more significant and animals face *intertemporal* considerations as a result (Ainslie, 1974; Loewenstein, Read, & Baumeister, 2003; Mazur, 1987). An intertemporal choice is any choice where the relevant outcomes are realised only at different points in time.

Consider that when a spider builds a web, energy must be expended to produce the silk and to spin the threads, and all other opportunities in the present (e.g., mating) must be forfeited. Building a web, like many other activities in the animal kingdom – from hibernating, to caching food, to searching for a mate – can therefore be construed in terms of an *intertemporal trade-off* between immediate and delayed outcomes. Natural selection has solved these problems with a number of effective mechanisms that enable animals to act now to secure future gains, often with relatively simple decisional rules (Mazur, 2007; Stevens, 2011). For instance, though it is possible, it is unlikely that the spider building her web mentally envisages and weighs up the future benefits she might stand to accrue for her patience. Instead, she is endowed with an adaptable but instinctual web-building proclivity, and is rewarded for her immediate efforts only after a delay by the misfortunes of some unlucky insect. The strategy has spread in web-building spiders over evolutionary time because the genes that coded for better and more efficient web-building outcompeted those that coded for alternative strategies. The same logic applies when an animal builds a burrow into which it can scurry at the sight of a predator – the burrow is created now to avoid potential future harms: but the burrow-builder need not anticipate any specific aggressor. The animal kingdom is replete with mechanisms that take the future into account to maximise the acquisition of delayed rewards and avoidance of delayed threats.

Humans have a domain-general mechanism for taking the future into account. We can imagine it in vivid detail, letting us conceive of narratives, embed these narratives into greater storylines, and ponder how things might turn out if we choose differently or enact diverse courses of behaviour. We spend much of our lives thinking about and imagining the future, meaning bountiful possibilities are evaluated in order to more adaptively decide what to do in the present. The capacity for *prospective cognition* is thus an enormously powerful psychological tool for decision-making, especially when the choices we are making have a temporal dimension.

*Figure 1.2.* Intertemporal trade-offs are ubiquitous in nature. A spider foregoes all other opportunities in the present to build a web that will only later deliver rewards. While the spider may not be fantasising about the future dinner her web will provide, humans spend much of waking life imagining the payoffs or threats that await us. Image by Shafquat Ameen, CC BY-SA 4.0.

Where does prospective cognition come from? Nothing in psychology exists devoid of its evolutionary history. In this thesis, evolutionary reasoning will therefore be used as a platform for hypothesis generation and as a method to address fundamental questions about the nature of prospection and its role in decision-making. This approach, perhaps best articulated by Niko Tinbergen in *On aims and methods of ethology* (1963), solves a number of conceptual problems that arise when addressing questions about "function" - a particularly notorious problem in decision-making research (what are the decisions *optimising?* what is the *value* upon which decisions are predicated?). Tinbergen asks four questions about any trait: what is its evolutionary function? How did it evolve? How does it develop? And how does it work, in terms of mechanisms? In the course of this thesis, I attempt to make inroads into each of these questions about the role of human prospective cognition in decision-making. This approach required me to work with a diverse range of methods and sample populations, including healthy adults and young children using both experimental and cross-sectional approaches.

The fourth of Tinbergen's questions listed above – "how does it work?" is the main concern of this thesis. I aim to elucidate the psychological processes that underlie the ability to shape our decisions in the here-and-now based on assessments of the future. I hope that in the process, some light will be shed on the psychological mechanisms themselves, as well as the evolutionary origin of these mechanisms. Intertemporal decision-making is especially consequential and widespread in human affairs. It is central to our choices about alcohol and drug use, saving for retirement, politics, dieting, economic investments, climate change action, education, sex, and romantic love. In all of these domains, decisions in the present have downstream consequences, both positive and negative.

### 1.4. The structure of this thesis

In chapter two, "Prospection and the present moment" I review the key concepts of this thesis, including intertemporal choice, mental time travel, and *episodic foresight*, which is defined as *the capacity to imagine future scenarios and adjust present decision-making and behaviour accordingly* (Suddendorf & Moore, 2011). Note that I sometimes also use the term *episodic future thinking* to refer to the simulation component only (absent the downstream adjustment of behaviour). In chapter two, I present a model that attempts to explain how prospective cognition is involved in intertemporal decision-making. Central to this model are anticipated emotions and predicted likelihoods. I argue that intertemporal choices can be made without episodic foresight, but that episodic foresight enables more flexible and adaptive intertemporal decision-making that takes into account the likelihood and value of delayed rewards. Imagining the future may encourage more prudent, less 'impulsive' choices (i.e. those that prioritise delayed outcomes). But it also makes little sense to be patient for a delayed reward that one anticipates will never materialize. Alongside this model, I also present a number of specific hypotheses that I proceed to test in later chapters of the thesis, such as the prediction that when people imagine the future to be dangerous, bleak, or harsh, their preferences should shift towards immediate, and thus more certain, rewards.

In chapter three, "The influence of episodic foresight on delay discounting and demand for alcohol", I present the results of an experimental study into the effects of cued episodic foresight on impulsivity in the domains of intertemporal decision-making and alcohol demand. While cuing participants to imagine positive future events reduced their delay discounting (thereby replicating a series of other experiments), it produced inconsistent, small, and unreliable effects on various indices of alcohol-related decision-making. This suggests that the effects of prospective cognition on impulsivity may be limited to particular domains, perhaps those with an explicit time dimension. This is a theme that runs through a number of the chapters in this thesis.

In chapter four, “Thinking about threats”, I review the various ways that humans remember or anticipate dangers. This chapter contains a taxonomy of threat-related cognition that connects the literature on anxiety with the literature on mental time travel. Specifically, this taxonomy comprises episodic (event-based) and semantic (knowledge-based) forms of both memory and foresight. After discussing the commonalities and differences between memory and foresight, and outlining the characteristics of the four parts of the taxonomy, I discuss various implications for adaptive decision-making and the study of anxiety disorders. Prospective cognition is a central feature of anxiety and a potent source of distress; and understanding its role is therefore critical. In chapter five, I present results from a cross-country analysis of the role of threat in intertemporal decision-making. The analysis is derived from a prediction outlined in the theoretical accounts of chapters two and four. Across countries, when life expectancy was lower, fewer people were willing to wait for a larger but delayed reward, and women had their first child at a younger age. The logic for the inclusion of age at first birth in this analysis is that intertemporal trade-offs cut across various domains including monetary preferences but also in deciding when to raise children. The results of this study, which held after controlling for global region and gross-domestic product per capita, dovetail with findings at the individual level to suggest that environmental threats can be an important predictor of intertemporal choices.

To directly address the causal influence of imagining future threats on decision-making, I conducted an experiment, presented in chapter six, in which participants were cued to imagine future threats or future positive events while making intertemporal choices and risk-taking decisions. Imagining either type of future scenario led participants to discount the value of future rewards significantly less than engaging in emotionally neutral control imagery, but foresight had no effect on risk-taking in a standard laboratory task. Thus, while these results once again replicate previous findings that cued foresight can reduce delay discounting (in the largest sample of this phenomenon to date), they indicate that this effect is not dependent on emotional content and suggest further boundaries on its generalizability to other decision-making domains.

In chapter seven, I survey some of the most critical functions of the prospective mind. In each case, I argue that human metacognition – our ability to think about our thinking – bolsters these capacities because it means people can reflect on and compensate for the natural limits of their foresight. For example, we make contingency plans because we appreciate that initial predictions may turn out to be wrong. I suggest that the processes involved in monitoring, controlling, and augmenting prospective cognition represent an important and understudied parallel of *metamemory* that should be called *metaforesight*. Chapter eight describes an experiment into the developmental origins of metaforesight: how do children acquire the ability to compensate for their future failures? I show that even children as young as four years old are capable of rapidly learning to set themselves reminders to compensate for future memory failures. Furthermore, the selective deployment of this behaviour in a manner congruent with cognitive demand increased throughout childhood – in line with a body of literature on the development of future-directed cognitive control.

In a general discussion in chapter nine, I survey the key themes of the thesis with close reference to the insights gleaned in specific chapters. I suggest avenues for future research into the mechanisms and development of prospection in decision-making, as well as the clinical relevance of the findings in this thesis. Finally, I reflect more broadly on the evolutionary legacy of prospective cognition in human decision-making and explore ways it could be leveraged to steer us forwards.

## Chapter Two. Prospection and the present moment

**Bulley, A.,** Henry, J.D., & Suddendorf, T. (2016). Prospection and the Present Moment: The role of episodic foresight in intertemporal choices between immediate and delayed rewards. *Review of General Psychology, 20(1), 29–47.* http://doi.org/10.1037/gpr0000061

### Preface and details of contribution to authorship:

In this interdisciplinary review the key concepts of this thesis are defined, including intertemporal choice, mental time travel, and episodic foresight. The chapter presents a model of prospective cognition in intertemporal decision-making that incorporates anticipated emotions and predicted likelihoods. It also presents a number of specific hypotheses that are tested in later chapters of the thesis. I conceived the project, did the research, and wrote the first draft of the paper. Julie D. Henry and Thomas Suddendorf provided critical revisions.

**Abstract**

Humans are capable of imagining future rewards and the contexts in which they may be obtained. Functionally, intertemporal choices between smaller but immediate and larger but delayed rewards may be made without such episodic foresight. However, we propose that explicit simulations of this sort enable more flexible and adaptive intertemporal decision-making. Emotions triggered through the simulation of future situations can motivate people to forego immediate pleasures in the pursuit of long-term rewards. However, we stress that the most adaptive option need not always be a larger later reward. When the future is anticipated to be uncertain, for instance, it may make sense for preferences to shift toward more immediate rewards, instead. Imagining potential future scenarios and assessment of their likelihood and affective consequences allows humans to determine when it is more adaptive to delay gratification in pursuit of a larger later reward, and when the better strategy is to indulge in a present temptation. We discuss clinical studies that highlight when and how the effect of episodic foresight on intertemporal decision-making can be altered, and consider the relevance of this perspective to understanding the nature of self-control.

## 2.1. Introduction

Preparation for the future is a critical aspect of complex life. The causal directionality of time means that those traits that serve to bolster the survival and reproductive success of an organism in the future are favoured by natural selection. It is perhaps unsurprising, then, that cognition in animals is fundamentally future-oriented, expressed in many different types of goal-driven behaviour (Seligman, Railton, Baumeister, & Sripada, 2013; Suddendorf & Corballis, 1997). To pursue future rewards, individuals must at times forgo more immediate opportunities and a large body of research has examined how such decisions are made when both human and non-human subjects are presented with a choice between smaller but immediate rewards, and larger ones likely available at some point in the future (Berns, Laibson, & Loewenstein, 2007; Loewenstein et al., 2003; Peters & Büchel, 2011). In these so-called *intertemporal choice* tasks a decision-maker must indicate a preference for one of these options to the exclusion of the other. For instance, pigeons may peck one button to receive some grain now, or peck another button and wait six seconds for a larger payload (Mazur & Logue, 1978). Though human studies typically involve considerably longer delays, the structure of the tasks is often the same. For example, participants may be required to click one button to indicate a preference for $6 now, or another to indicate a preference for $10 after a wait of 30 days (J. B. Richards, Zhang, Mitchell, & de Wit, 1999). Such behavioural choices may reflect future-oriented decision-making mechanisms that incorporate information about the costs and benefits of future possibilities. Here we examine how the capacity to mentally simulate future situations influences these decisions.

Humans can engage in mental time travel into the future, or *episodic foresight,* a capacity that allows details of a potential future reward outcome and its context to be simulated and to thereby inform decision-making (Atance & O'Neill, 2001; Schacter et al., 2007; Suddendorf, 2010; Suddendorf & Corballis, 1997, 2007; Suddendorf & Moore, 2011). The open-ended capacity to imagine potential future scenarios confronts humans with many opportunities and thus with choices about what to pursue when. Clearly, human intertemporal decision-making can be very complex as a result, involving plans that can span decades, diverse sub-goals and if-then contingencies. It remains uncertain, however, whether mental time travel is required to act adaptively even in simple standard intertemporal choice tasks. Indeed, there is now a considerable literature showing that non-human animals and people with hippocampal amnesia, who appear to lack or be severely limited in their episodic foresight, are nonetheless able to pursue larger delayed payoffs, at least over short timeframes (Kwan et al., 2012; Stevens & Stephens, 2008). This suggests that simpler mechanisms may drive such choices.

In this review, we argue that even if a capacity for episodic foresight may not be a necessary prerequisite for making future-oriented intertemporal choices, it offers tremendous additional *flexibility* over other mechanisms. We focus on the role of episodic foresight in modifying decisions in standard intertemporal choice situations; that is, when a decision must be made between an immediate and a delayed reward where one option is chosen to the exclusion of the other. Simulating future rewards during intertemporal choice situations may trigger emotions that motivate people to forego immediate pleasures in pursuit of longer-term goals. This has been considered a defining factor in the evolution of foresight and a critical human ability (Baumeister & Masicampo, 2010; Boyer, 2008). However, we highlight that imagining the future does not necessarily lead people to forgo immediate temptations. For instance, if one foresees an uncertain or threatening future it may be more adaptive to indulge in the present, given that future rewards may not materialize. Therefore, we argue that episodic foresight affords adaptive flexibility in simple intertemporal choice situations – serving to shift preferences either towards long-term rewards or towards immediate gratification, depending on what one anticipates the future will hold. We discuss the implications of this view with regards to the nature of self-regulatory resources and outline evidence of alterations in the way episodic foresight may shift preferences in the context of clinical psychopathology, neurodegenerative disease and normal adult aging.

### 2.2. Episodic foresight as prospective cognition

Episodic foresight is not a unitary entity, but instead requires a suite of interacting component capacities and operations including some degree of self-awareness, as well as the capacity to entertain meta-representations and mental attributions (D'Argembeau, Ortoleva, Jumentier, & Van der Linden, 2010; Redshaw, 2014; Suddendorf & Corballis, 1997, 2007; Suddendorf & Redshaw, 2013). Episodic foresight forms part of a general constructive process of mental time travel responsible for the simulation of both past and future episodic events (Buckner & Carroll, 2007; Hassabis & Maguire, 2009; Suddendorf & Corballis, 1997). Evidence from cognitive neuroscience, brain lesion patients, developmental psychology and phenomenological analyses converge to show fundamental links between episodic foresight and episodic memory (e.g. Addis et al., 2007; Busby & Suddendorf, 2005; D'Argembeau & Van Der Linden, 2004; Hassabis, Kumaran, Vann, & Maguire, 2007; Schacter et al., 2012; Spreng, Mar, & Kim, 2009;

Szpunar, 2010). Nonetheless, there are some important differences (Suddendorf, 2010) including differential reliance on cognitive operations such as *recombination* (Weiler, Suchan, Koch, Schwarz, & Daum, 2011). Episodic foresight relies on components from memory to generate potential future scenarios (Hassabis & Maguire, 2009; Schacter et al., 2007; Suddendorf & Busby, 2003), but this is not to say that these simulations can only be mere repetitions of past events. Instead, entirely novel constellations of possibilities can be constructed by recombining various constituent elements, such as actors, actions and objects, just as one can recombine words into novel sentences (D. T. Gilbert & Wilson, 2007; Suddendorf & Corballis, 2007; Suddendorf & Redshaw, 2013).

The capacity to imagine various possible future contingencies has critical implications for adaptive decision-making (Suddendorf & Busby, 2005). Indeed, according to Suddendorf & Moore (2011) episodic foresight entails not only the simulation of future scenarios but also the capacity to organise current action in view of anticipated events. In adult humans, such future-directed decisions can be focused on achieving short-term goals such as shopping for tomorrow's dinner or planning a surprise party, as well as long-term goals such as saving for retirement (Suddendorf & Redshaw, 2013; van Slageren, 2003). Episodic foresight occurs voluntarily, but also involuntarily (i.e. without conscious effort) in the course of everyday life (Berntsen & Jacobsen, 2008; D'Argembeau, Renaud, & Van Der Linden, 2011; Finnbogadóttir & Berntsen, 2013), and may constitute an on-going and underlying process of planning and preparing for future possibilities with regards to personal goals (Baird, Smallwood, & Schooler, 2011; Demblon & D'Argembeau, 2014; Smallwood & Andrews-Hanna, 2013; Stawarczyk, Cassol, & D'Argembeau, 2013). Indeed, episodes of future-oriented mind-wandering have been linked to the activity of the 'default mode network' of cortical regions usually active during periods of task-unrelated rest. Such findings suggest that people often resort to imagining future possibilities when external task demands are low (Burgess, Dumontheil, & Gilbert, 2007; Corballis, 2012, 2013; Mason et al., 2007; Smallwood, Tipper, et al., 2013; Smallwood & Schooler, 2015; Spreng & Grady, 2010).

Future-oriented cognition refers to a multidimensional array of cognitive processes, and attempting to delineate these processes has led to the identification of prospective counterparts to well-established subtypes of memory (Atance & O'Neill, 2001; Osvath & Martin-Ordas, 2014; Raby & Clayton, 2009; Suddendorf & Corballis, 2007; Szpunar, Spreng, & Schacter, 2014). For instance, Suddendorf and Corballis (2007) outline prospective counterparts to episodic, semantic and procedural memory, which differ in the demands they impose on semantic, episodic or procedural knowledge structures, respectively. Szpunar et al. (2014) further taxonomize prospective cognition into semantic and episodic forms of simulation, prediction, intention and planning, where each mode of future-oriented cognition has particular distinctive characteristics and component processes. However, the delineations between these different forms of prospective cognition are not absolute. In fact, the various forms are highly interrelated. For instance, it is well established that semantic knowledge plays an important, if not critical, role in the generation of episodic future simulations (Irish, Addis, Hodges, & Piguet, 2012; Irish & Piguet, 2013).

In sum, episodic foresight can be considered a form of prospective cognition that is hallmarked by the explicit mental representation of possible future events or outcomes and their embedding into larger causal narratives (Suddendorf & Corballis, 1997). In intertemporal choice tasks, episodic foresight therefore allows humans to create detailed and vivid mental simulations of possible future rewards and the contexts in which they may be obtained.

### 2.3. Future-oriented behaviour in the absence of episodic foresight

Examples of behaviours that appear future-oriented are ubiquitous in the animal kingdom. Even single-celled organisms can come to adjust their metabolism or locomotive rate in preparation for changing oxygen levels or periodic humidity, respectively (Saigusa, Tero, Nakagaki, & Kuramoto, 2008; Tagkopoulos, Liu, & Tavazoie, 2008). African termites build complex mounds with sophisticated thermoregulatory ventilation systems that ensure adequate gas exchange and ambient temperature in light of forthcoming changes in environmental conditions (Korb, 2003; Korb & Linsenmair, 1999), and so forth. It is uncontroversial to assume that these activities do not require any explicit mental representation of future events. Instead, these examples illustrate the power of emergent complex systems evolved over successive generations in response to regularities in the environment.

There are, however, more contentious examples of apparent future-directed decision-making and behaviour in other non-human animals with complex brains. This includes the food caching of Western scrub jays, for instance, and the carrying of stones or sticks by great apes for future use in cracking nuts or termite fishing, respectively (Boesch & Boesch, 1983, 1984; Correia, Dickinson, & Clayton, 2007; Raby, Alexis, Dickinson, & Clayton, 2007). Although impressive, even these behaviours need not necessarily be explained by evoking a capacity for episodic foresight, but may instead reflect fixed action patterns or instinct, learned associations, complex environmental scaffolding, semantic or implicit forms of prospection, and any combination of these (Raby & Clayton, 2009; Suddendorf & Corballis, 2007, 2010).

Whether or not some nonhuman animals have a capacity for episodic foresight, it is clear that many species demonstrate adaptive behaviour in situations that can be described as intertemporal choices. Decisions have to be made about whether *now* is the time for actions that may have future benefits (such as building a burrow) that may be in conflict with more immediately rewarding actions such as seeking food rewards. Foraging itself includes many examples that can be construed as intertemporal decisions. Food caching, for instance, reflects a choice between consuming a reward now or saving it for a later time when its value may be higher, whether or not the animal is aware of this (Stevens & Stephens, 2008). Animals that cache enough food prior to food-scare future months will have a selective advantage over those that do not, and so mechanisms driving appropriate future-directed behaviours can spread. Other examples can be derived from questions about what to eat. An animal may, for instance, either eat an unripe fruit now or wait for it to ripen and reap the benefits of better taste and added nutrition (Dasgupta & Maskin, 2005; Fawcett, McNamara, & Houston, 2012; Stevens & Stephens, 2008). However, just because a behaviour can be described as a response to an intertemporal choice in terms of the options available and their consequences does not mean that it must be driven by explicit representations of future outcomes and a deliberate decision between the options. Unripe fruit may simply taste bad and be shunned without any understanding that it may ripen later.

In this section, we have outlined that many organisms exhibit some predictive capacities for action in the face of an uncertain future and frequently face situations that can be described as intertemporal choices, in which a decision must be made with outcomes that play out over time. Next we turn to the experimental examination of such choices.

### 2.4. Delay discounting and the delay of gratification

When given a choice between a smaller immediate reward, and a larger but delayed one, both humans and non-human animals tend to prefer the immediate (albeit smaller) option (Ainslie, 1974; Mazur, 1987; Stephens & Anderson, 2001). However, under some circumstances the delayed option is preferred, especially if the delay is small or the perceived value of the delayed reward large. In humans, delay discounting is most often indexed using intertemporal choice tasks, in which people are presented with a series of hypothetical choices between monetary amounts available immediately or after varying delays. In such tasks, future rewards decrease in subjective value as they move further away in time, a delay discounting effect sometimes modelled by an exponential curve, but probably more accurately by a hyperbolic function (Berns et al., 2007; Dasgupta & Maskin, 2005; Green & Myerson, 1996; Mazur, 1987; Shoji & Kanehiro, 2012). The steepness of the discounting curve is indicative of individual preferences, such that for an individual with a steeper discounting curve rewards more rapidly lose subjective value with increasing delays.

In classic experiments, children have been shown to find 'delaying their gratification' difficult when offered a choice between eating a single marshmallow now, or waiting to receive an additional second marshmallow after some time (Mischel, Ebbesen, & Zeiss, 1972). Attempting to delay gratification when presented with a tasty reward involves both the initial choice to be patient (akin to the hypothetical money choices discussed above) as well as a subsequent on-going effort to resist indulging in the face of temptation. The degree to which an individual is prepared to wait in childhood has been found to robustly predict subsequent academic, personal and social successes even 40 years later in life (Mischel et al., 2011; Mischel, Shoda, & Rodriguez, 1989; Schlam, Wilson, Shoda, Mischel, & Ayduk, 2013; Shoda, Mischel, & Peake, 1990), though a more recent replication attempt has tempered the strength of these claims somewhat (Watts, Duncan, & Quan, 2018). An individual tendency to prefer immediate but smaller rewards over larger but delayed ones has conversely been associated with a range of maladaptive behaviours including substance abuse, physical inactivity and pathological gambling (Bickel & Marsch, 2001; Dixon, Marley, & Jacobs, 2003; Story, Vlaev, Seymour, Darzi, & Dolan, 2014).

The fact that the future is inherently uncertain may be responsible, at least in part, for the phenomenon that rewards become subjectively less valuable with increasing delays until their receipt (Fawcett et al., 2012; Loewenstein et al., 2003). After all, the future rewards may never eventuate or may be inferior to those promised. For instance, another individual may eat some or all of the fruit one has been waiting to ripen. If this is believed to be likely then *immediacy*, defined here as a behavioural tendency to select a smaller but sooner reward in lieu of a larger later one, is the more adaptive response, and delayed rewards will be more steeply discounted as a result (Houston & McNamara, 1988). A preference for, or selection of, immediate smaller rewards has also sometimes been referred to as 'impulsivity' (Ainslie, 1974; Rachlin, 1974), although we will argue below that such a preference may also be caused by a consideration of the future.

A tendency to discount the subjective value of delayed rewards has been documented in numerous animal species from fish to great apes (Fawcett et al., 2012;

Mühlhoff, Stevens, & Reader, 2011; Rosati, Stevens, Hare, & Hauser, 2007). Most animal species only wait for a few seconds for delayed benefits (e.g. Ainslie, 1974; Mazur, 1987), but at least some species can delay gratification for somewhat longer (Fawcett et al., 2012; Logue, 1988; Rosati et al., 2007; Stevens, Hallinan, & Hauser, 2005). The extent to which an animal species may delay the receipt of rewards appears to be linked to their ecological context. For example, animals that evolved in environments in which delayed rewards were less certain may have an increased propensity towards immediate gratification. As already noted, the more uncertain a larger delayed option is, the more advantageous it is to hold a preference for an immediate reward (Fantino, 1995). On the other hand, an evolved propensity for tool use or for less opportunistic foraging strategies may encourage greater tolerance for delays because these strategies generally require more waiting from the onset of behaviour to the acquisition of a reward (Addessi, Paglieri, & Focaroli, 2011; Stevens et al., 2005).

Without linguistic instruction, animal studies must rely on the subjects' experience with the rewards and contingencies. For instance, subjects may be presented with a choice between two tools. Pulling one of these tools results in two food pellets, while pulling the other results in six food pellets. Initially, there is no time lag, but then a one second delay is added between selecting the larger reward tool and the receipt of the reward each time the subject choses it, allowing for an *indifference point* to be determined where the animal selects the delayed and immediate rewards equally often (Stevens et al., 2005). In *accumulation* tasks a reward is available at any time but *builds up* the longer the animal waits. Gaining a larger reward hence involves inhibiting the taking of the reward, as that would end the accumulation process (e.g. Anderson, Kuroshima, & Fujita, 2010; Beran, 2002; T. A. Evans & Beran, 2007; Pelé, Dufour, Micheletta, & Thierry, 2010; Pelé, Micheletta, Uhlrich, Thierry, & Dufour, 2011). Finally, *exchange tasks* require an animal to keep a small reward in their possession for a period of time before trading it back to the experimenter for a bigger reward (Dufour, Pele, Sterck, & Thierry, 2007; Leonardi, Vick, & Dufour, 2012). It remains debatable to what extent these different methodologies track the same capacities (Addessi et al., 2013) and to what extent they are comparable to standard human intertemporal choice tasks. For instance, concern has been raised about how animals interpret the delays within and between trials and there is evidence that patterns of apparent temporal discounting change as a result of changes to the salience of 'post-reward delays' between trials (T. C. Blanchard, Pearson, & Hayden, 2013; J. M. Pearson, Hayden, & Platt, 2010).

Notwithstanding debates about the interpretation of particular animal studies (T. C. Blanchard et al., 2013), the bulk of the research suggests that several species (e.g. rats, pigeons, dogs, monkeys and great apes) have some capacity to delay gratification in pursuit of larger future rewards, even if only over very short delay periods (Anderson et al., 2010; T. A. Evans & Beran, 2007; Leonardi et al., 2012; Osvath & Osvath, 2008; Reynolds, de Wit, & Richards, 2002; Stevens et al., 2005; Stevens, Rosati, Heilbronner, & Mühlhoff, 2011; Stevens & Stephens, 2008). Interestingly, the discounting rates of humans and nonhuman animals are quite similar when rewards are directly consumable food or water rather than money (Jimura, Myerson, Hilgard, Braver, & Green, 2009; Rosati et al., 2007), and in some contexts humans have even been found to be *less* patient than chimpanzees when waiting for food (Rosati et al., 2007). Nonetheless, this should not obscure the fact that most animals only wait for a few seconds for a reward, and chimpanzees for a few minutes (e.g. Dufour et al., 2007), whereas humans can delay their gratification for days, months or even years. Indeed, self-control in the face of immediate temptations continues to be considered a defining human ability (Baumeister, 2014; Baumeister & Tierney, 2011; Herrmann, Misch, Hernandez-Lloreda, & Tomasello, 2014; Vohs et al., 2014).

### 2.4.1. Neural mechanisms and the role of the hippocampus

A full discussion of the neural mechanisms underpinning intertemporal decision-making is beyond the scope of this article (for review see Peters & Büchel, 2011). However, in brief, mechanistic accounts of delay discounting have been proposed in which separate neural systems are involved in the valuation of immediate versus delayed rewards (McClure, Ericson, Laibson, Loewenstein, & Cohen, 2007; McClure, Laibson, Loewenstein, & Cohen, 2004). Specifically, limbic structures including the striatum may encode the value of immediately available rewards while frontal regions including the dorsolateral prefrontal cortex may encode the value of temporally protracted ones. However, it has also been argued that there may be a single valuation system that weighs the value of rewards, irrespective of the delay to their receipt (Kable & Glimcher, 2007; Peters & Büchel, 2011).

The ventromedial prefrontal cortex (vmPFC, sometimes synonymous with orbitofrontal cortex) and ventral striatum (VS) appear to play a crucial joint role in the temporally extended valuation of rewards by encoding or representing their value (Peters & Büchel, 2011). Activity in the VS and vmPFC is frequently associated with the value of future rewards during intertemporal choice tasks (Kable & Glimcher, 2007), and lesions to the vmPFC increase delay discounting rates (Sellitto, Ciaramelli, & di Pellegrino, 2010). Perhaps most critically, medial temporal (including hippocampal) brain regions usually implicated in the construction of explicit mental scenes are generally not reported to be active during standard intertemporal choice tasks (Ballard & Knutson, 2009; Kable & Glimcher, 2007; Peters & Büchel, 2009). Again, this suggests that when encoding the value of future rewards, the whole suite of neural regions involved in the episodic mental representation of future possibilities may not necessarily be involved.

Further evidence from studies of people with hippocampal amnesia support the argument that making intertemporal choices generally, and the delay of gratification, are not reliant on episodic foresight (Kwan et al., 2012). Damage to the medial temporal lobes usually results in profound difficulties imagining personal future events (Hassabis et al., 2007; Race, Keane, & Verfaellie, 2011; Verfaellie, Race, & Keane, 2012), but nonetheless patients with this damage can select delayed rewards and do exhibit somewhat normal delay discounting rates (Craver, Cova, et al., 2014; Kwan et al., 2012; Kwan, Craver, Green, Myerson, & Rosenbaum, 2013). On account of findings like these, patients with hippocampal amnesia are now no longer considered to be wholly "stuck in time" as was once thought, despite having no ability to imagine personal future events in the most severe cases (Craver, Kwan, Steindam, & Rosenbaum, 2014). Interpretations of these findings, however, should be cautious given that other compensatory strategies for making intertemporal decisions and delaying gratification may have developed in response to the brain damage. Nevertheless, taken together, the most parsimonious explanation for current data as outlined in this section is that episodic foresight is not necessarily required either for the systematic subjective devaluation of rewards over at least short periods of time, or for electing to receive greater rewards after a delay.

### 2.4.2. Flexibility in intertemporal choice

As mentioned, delay discounting rates may vary between species as a function of their ecological conditions (Fawcett et al., 2012). However, even within the same species, and within the same individual, discounting rates may vary in relation to specific environmental contingencies. In humans, for instance, soldiers in times of active service exhibit steeper delay discounting than demographically matched controls, perhaps because of the heightened risk inherent in the personal future of the soldiers (Lahav, Benzion, & Shavit, 2011). Likewise, when a delayed reward becomes less probable in an intertemporal choice task because the administering experimenters have proven to be untrustworthy, bonobos are less prone to delay their gratification (Stevens et al., 2011).

Young children are similarly susceptible to changing levels of reward uncertainty, and become less inclined to wait for a second marshmallow if their experimenter fails to uphold a previously assured promise (Kidd, Palmeri, & Aslin, 2013). It makes little sense to be patient for a reward that is unlikely to materialize.

In addition to experimental evidence showing that discounting rates amongst children are strongly influenced by the probability that a future reward will actually materialise (Kidd et al., 2013; Mahrer, 1956), there is also evidence linking parental reward inconsistency in childhood with steeper discounting rates in later life. Presumably, early exposure to reinforcement uncertainty fosters a preference for immediate rewards as this has proven during development to be the more effective strategy for maximizing resource acquisition (Mauro & Harris, 2000; Patock-Peckham, Cheong, Balhorn, & Nagoshi, 2001; Patock-Peckham & Morgan-Lopez, 2006). One critical aspect of environmental uncertainty is an increased risk of death. When mortality risk is high, behavioural strategies that favour the acquisition of immediately available rewards may be an adaptive response. This is because the individual is less likely to be alive to capitalize on delayed rewards. As such, development in highly uncertain environments has been linked to more present-focussed decision-making and behaviour, as has exposure to cues of mortality risk (E. M. Hill, Jenkins, & Farmer, 2008; Kruger & Zimmerman, 2008; Pepper & Nettle, 2013, 2014; M. Wilson & Daly, 1997).[1]

In this section, we have outlined how decision-makers may adjust their preferences for immediate and delayed rewards depending on the environmental circumstances in which they developed, or to which they are exposed. Specifically, an individual may come to prefer immediate over delayed rewards more so after learning that future rewards are unlikely to materialize (via development in uncertain environments), or that one may not be around to reap delayed rewards if and when they do arrive (e.g., by inferring one's risk of untimely death). However, humans are also capable of the flexible assessment of the value and likelihood of specific future rewards and the contexts in which they are to be received because they can simulate future possibilities. Episodic foresight allows people to shape the future based on comparisons of multiple future rewards and analyses of future contexts, sub-goals and if-then contingencies. In light of imagined future situations,

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[1] It is worth noting that the majority of these findings do not take into account the possibility of genetic confounding. Given the high heritability of delay discounting, parents provide both a rearing environment as well as the genes predisposing children to the trait, and observed relationships between environments and outcomes could be due to this underlying confound (Plomin, DeFries, Knopik, & Neiderhiser, 2016; Sherlock & Zietsch, 2018; Zietsch, 2016).

humans can adjust their preferences for immediate and delayed rewards in a highly flexible and adaptive manner - a point to which we now turn.

### 2.5. The role of episodic foresight in modifying intertemporal choices

Recent evidence suggests that engaging in episodic foresight while making intertemporal choices can result in significantly reduced rates of delay discounting (Benoit, Gilbert, & Burgess, 2011; Y.-Y. Cheng, Shein, & Chiou, 2012; Daniel, Said, Stanton, & Epstein, 2015; Daniel, Stanton, & Epstein, 2013b, 2013a; H. Lin & Epstein, 2014; Liu, Feng, Suo, Lee, & Li, 2012; Peters & Büchel, 2010). For instance, in the behavioural component of an fMRI study, Peters and Büchel (2010) provided participants with a series of intertemporal monetary choices between a fixed smaller reward available immediately, and larger rewards delayed by different amounts of time. In half of the trials participants were cued about personally relevant events that were timed concurrently with the delayed options before making their decision, while in the other half of trials participants simply indicated their choice. The event cues were derived from a pre-test interview with the participants about real future scenarios that they had planned for the days of the delayed reward delivery. This meant that participants were presented with a standard intertemporal choice (e.g. between 20€ now, or 35€ in 45 days) and in the episodic condition reminded about events in their personal future (e.g. vacation in Paris) while making this choice. As is typical of intertemporal choice studies, participants were told that one of the trials from the task would be selected at random, and the specified reward allocated after the chosen delay. Results indicated that in the episodic cue condition, participants were more prone to choose larger but delayed rewards. In other words, preferences tended to shift away from immediate gratification and towards long-term outcomes when participants were cued with personally relevant future events before making their choices. This effect was associated with individual differences in the degree of simulated episodic imagery, such that those participants who reported more frequently and more vividly imagining the future during the task were more inclined to choose the delayed rewards. In a separate but similar study, this reduction in discounting rates was also associated with the emotional intensity of the imagined episode, such that more emotionally intense imagery was linked to a greater tendency to choose delayed over immediate rewards (Benoit et al., 2011).

Interestingly, preferences in such modified intertemporal choice tasks have been found to shift towards future rewards whether participants are asked to imagine the actual consumption of a delayed reward (e.g. Benoit et al., 2011; Palombo, Keane, & Verfaellie, 2014), events around the time of future reward receipt (Daniel et al., 2013b; Kwan, Craver, et al., 2015; Peters & Büchel, 2010), or future events in general (Y.-Y. Cheng et al., 2012). For example, in Benoit et al.'s (2011) study, participants were instructed to vividly imagine spending the specified delayed reward amount in a preordained scenario (at the pub) whilst making their intertemporal choices, whereas in Cheng et al.'s (2012) experiment one, participants were asked to imagine a typical day in their life four years from the present before starting a separate intertemporal choice task. Despite these disparate methods, engaging in episodic foresight shifted preferences towards future outcomes. In one recent study it was found that the extent of this preference shift was unrelated to the amount of previous experience that participants had with the *content* of the simulated future events (Sasse, Peters, Büchel, & Brassen, 2015). Imagining meeting both a celebrity (unfamiliar) and a family member (familiar) in a café attenuated the rate of delay discounting in a similar way.

A number of further studies have replicated the attenuating effect of engaging in episodic foresight on delay discounting, and identified a number of additional factors that may be involved (Daniel et al., 2013b, 2013a; Dassen, Jansen, Nederkoorn, & Houben, 2016; H. Lin & Epstein, 2014; Liu, Feng, Chen, & Li, 2013; O'Neill, Daniel, & Epstein, 2015). Importantly, some of these recent studies have included more robust control conditions, such as episodic thinking about recent or soon-to-be events (Daniel et al., 2015; H. Lin & Epstein, 2014), or episodic thinking about a story with vivid imagery (Daniel et al., 2013b, 2013a). The effect of episodic foresight on delay discounting has also been documented to have significant real life implications in contexts where a choice must be made between immediate gratification and long-term goals: both obese women and children tempted with gratifying unhealthy foods reduced their caloric intake as a result of episodic foresight during *ad libitum* eating (Daniel et al., 2015, 2013b). This effect has also recently been shown to occur in a naturalistic food-court setting with obese or overweight women (O'Neill et al., 2015). Similarly, Dassen et al (2015) report that a group of healthy female undergraduates consumed less calories during free access to snacks when simultaneously engaging in food-related episodic foresight (Dassen et al., 2016).

In addition to the aforementioned experimental effects, recent correlational studies have also suggested a link between individual differences on episodic foresight measures and a preference for delayed over immediate rewards. Firstly, Bromberg et al (2015) demonstrated that the vividness with which healthy adolescents imagined the future (as assessed using a form of autobiographical interview) was negatively correlated with their delay discounting rate (Bromberg, Wiehler, & Peters, 2015). Secondly, a greater tendency to engage in task-unrelated mind-wandering (shown to frequently involve mental time travel into one's personal future during everyday life) has also been associated with reduced delay discounting (Smallwood, Ruby, & Singer, 2013). Both of these correlational effects may reflect a similar process to when episodic foresight is explicitly cued during intertemporal choice tasks, such that a greater tendency to generate vivid simulations of the future during daily life may engender a greater consideration of the future consequences of the choices one makes in the present (e.g. Peters & Büchel, 2010).

Kurth-Nelson, Bickel, and Redish (2012) propose a theoretical model that accounts for the effect of episodic simulation on discounting. In this model, a cognitive search process that draws on working memory is responsible for valuing future rewards based on how readily they are located in mental representations of the future. When a reward is episodically simulated, it becomes easier for the search process to find. Empirical support for this model was provided in a study by H. Lin and Epstein (2014), who found that the effect of episodic foresight on delay discounting was moderated by visual working memory capacity. Specifically, participants with higher working memory capacity derived a greater reduction in discounting rates from episodic foresight. Also consistent with predictions from Kurth-Nelson et al.'s (2012) model about the importance of cognitive resources are studies showing that working memory limitations and load increase discounting rates (Hinson, Jameson, & Whitney, 2003; Shamosh et al., 2008), that working memory training can reduce discounting rates (Bickel, Yi, Landes, Hill, & Baxter, 2011), and that working memory capacity is critically implicated in the mental construction of scenes during episodic foresight (P. F. Hill & Emery, 2013).

Finally, also providing support for a relationship between engaging in imagining future events and a shift towards choosing delayed rewards, people with hippocampal amnesia do not show the same reduction in delay discounting rates seen in neurotypical volunteers when cued to imagine specific future reward outcomes during intertemporal choice tasks (Palombo et al., 2014). As noted earlier, people with episodic amnesia experience profound difficulties imagining novel future events (Hassabis et al., 2007; Race et al., 2011; Verfaellie et al., 2012), so it is perhaps unsurprising that their discounting rates were unaffected by cues to engage in specific episodic imagery about receiving future rewards. However, a recent study by Kwan et al. (2015) cued people with hippocampal amnesia to imagine general future events timed concurrently with delay options during an intertemporal choice task, and found reduced delay discounting in this condition. Kwan et al. (2015) noted that their cuing paradigm, which asked participants to imagine planned or plausible general future events like a wedding anniversary, diverged from the paradigm used in Palombo et al. (2014), in which amnesic participants were cued to imagine specific reward consumption (e.g. "Imagine spending $42 at a theatre in 2 months"). Kwan et al.'s paradigm therefore represents a potentially more challenging episodic foresight task, and this may account for the differences in the results between these two studies. Interestingly, the two individuals with the most extensive bilateral medial temporal lobe damage were least responsive to the effect of instructions to engage in episodic foresight on delay discounting rates in the study by Kwan et al. (2015). Taken together, these studies suggest that the relationship between episodic foresight and intertemporal choice may depend on the content and specificity of what is (or can be) imagined. This said, hippocampal damage in humans has been shown to produce characteristically inflexible and maladaptive decision-making under circumstances that require the recombinant manipulation of information (Rubin, Watson, Duff, & Cohen, 2014), which, as noted earlier, is a process thought to underpin episodic foresight (Suddendorf & Corballis, 1997, 2007). Consequently, while hippocampal amnesia may not preclude the valuation of future rewards, it may impede an ability to *modify* decisions about these rewards by simulating them and the context of their receipt (Kwan et al., 2015).

### 2.5.1. Episodic foresight can shift preferences towards immediate rewards

The previous section outlines how episodic foresight may engender a greater tendency to select larger but delayed rewards in intertemporal choices. Indeed, Boyer (2008) argued that the main adaptive function of episodic foresight may be to encourage future-oriented behaviour by countering the discounting of delayed rewards. However, such intensive research focus on how episodic foresight may facilitate delayed gratification may have obscured the *flexibility* that episodic foresight promotes during intertemporal choices. Simulating future possibilities may result in either a decreased or an increased preference for immediate rewards (Lempert, Porcelli, Delgado, & Tricomi, 2012; Liu et al., 2013; Miloyan, Bulley, & Suddendorf, 2016). As discussed earlier, a preference for immediate gratification can at times be adaptive. Imagining a future where delayed rewards are less likely to materialize, have less value, or negative emotions are anticipated (thereby indicating negative future contexts), may produce a shift in preferences towards immediate rewards.

Some initial experimental evidence supports this proposition. For instance, imagining negatively valenced possible future events during an intertemporal choice task can lead to *increased* delay discounting rates (Liu et al., 2013), as can high levels of explicit worry (Worthy, Byrne, & Fields, 2014). Liu et al. (2013) reported that when participants engaged in episodic foresight about emotionally aversive events such as an illness or a traffic accident, they were significantly more prone to choose immediate over delayed rewards while making intertemporal choices. Analogously, Worthy et al. (2014) demonstrated that high levels of worry (a preoccupation with thoughts about potential negative future events) were related to an increased preference for immediate rewards. Furthermore, participants have been found to have a greater preference for immediate (smaller) rewards after engaging in future thinking about a stressful upcoming event, but not a neutral one (Lempert et al., 2012). Lempert et al. (2012) suggest that in contrast to studies illustrating amplified preferences for delayed rewards after the simulation of positive future events (e.g. Benoit et al., 2011; Peters & Büchel, 2010), foreseeing a *stressful* future context may “precipitate a bleak view of the future” and shift preferences towards immediately available rewards. These findings show that prospection during intertemporal decision-making need not equate to an enhanced preference for delayed rewards. Instead, engaging in episodic thinking about potential negative future possibilities may serve to underscore the uncertainty of the future (or reduce the perceived probability of the future reward), triggering immediacy in the present moment as a strategy to secure available and certain resources (Lempert et al., 2012; Liu et al., 2013).

Episodic foresight means humans are capable of imagining their own death, and doing so may dramatically influence intertemporal choices for the obvious reason that it makes salient the natural end of how long it makes sense to delay gratification. In the context of imagining potentially fatal occurrences such as an illness or traffic accident (e.g. Liu et al., 2013), immediacy may become more adaptive given that the limit of one’s own future time horizon has been made salient and, ecologically speaking, patience is less likely to pay off when mortality risk is high (E. M. Hill et al., 2008; Kruger et al., 2008; Pepper & Nettle, 2013, 2014; M. Wilson & Daly, 1997). More direct tests are now needed to determine if simulating specific negatively valenced content flexibly adjusts discounting rates towards increased immediacy. For instance, does repeatedly imagining one’s promised second marshmallow being eaten by another child (over and above priming this risk) lead children to adjust their preferences towards the sure thing: the marshmallow they already have in their possession? Furthermore, does explicitly imagining one’s own untimely death result in a preference for immediate rewards? If so, campaigns aimed at reducing maladaptive health behaviours such as cigarette smoking by highlighting the risk of early death may paradoxically intensify preferences for immediate rewards (i.e. another cigarette). This is consistent with evidence showing increased delay discounting rates among participants from low socioeconomic backgrounds when exposed to mortality priming (Griskevicius, Tybur, Delton, & Robertson, 2011), and increased smoking intensity amongst individuals with strong cravings after cueing them with reminders of their mortality (Arndt et al., 2013).

In this section we have presented evidence that imagining future episodes might differentially shift preferences depending on the content of these imagined episodes. During an intertemporal choice, if one mentally envisages a rosy future where promised delayed rewards materialize, are of high quality, and are consumed, then a preference for larger delayed rewards becomes the better decision because patience in this context is more likely to pay off (Benoit et al., 2011; Daniel et al., 2013b; Peters & Büchel, 2010). However, we posit that if an imagined future is grim, with promised rewards withheld or of low quality, interruptions likely, or anticipated negative emotions rife (indicating negative future contexts), securing immediate rewards becomes a more adaptive decision-making strategy (Liu et al., 2013; Worthy et al., 2014). In sum, episodic foresight enables humans to consider diverse situations from various points in time and their links to present decisions. This confronts humans with complex intertemporal choices that can be prudently exploited. However, this is not to say that the adaptive function of episodic foresight is only the far-sighted delay of gratification in pursuit of large future rewards (see Ainslie, 2007; Baumeister & Masicampo, 2010; Boyer, 2008). Episodic foresight enables humans to flexibly respond to anticipated contingencies, which can also include an increased tendency to indulge in immediate temptations when the content of prospective images is grim.

### 2.6. How does episodic foresight influence decision-making in intertemporal choice situations?

For episodic foresight to modify choices in the present moment it must necessarily interface with evolutionarily older decision-making mechanisms evolved for the regulation of behaviour (Suddendorf & Busby, 2005). To this end, we highlight that mental simulations of possible future events provide value and likelihood information that influence decision-making. Specifically, the affective relevance, or emotional significance, of an imagined future contains *value* information about the outcome and context in question (Boyer, 2008; Gilbert & Wilson, 2007), while a gauge of the *likelihood* of various possible future outcomes may be deduced from imagining their occurrence and running simulations of possible steps to those futures (Kahneman & Tversky, 1981). How these two sources of information may adjust decisions in intertemporal choice situations is now outlined in turn.

### 2.6.1. Affective relevance

> All animals are on a voyage through time, navigating toward futures that promote their survival and away from futures that threaten it. Pleasure and pain are the stars by which they steer.
>
> – GILBERT & WILSON, 2007, p. 1351.

The emotional significance of a particular stimulus or event is an indicator of its biological value, providing a common appraisal metric for a diverse array of environmental occurrences (Panksepp, 1998). Value, in this biological sense, relates directly to the survival and reproductive success of an organism, and emotions may serve as signals by proxy of how a particular state, behaviour, stimulus or event relates to these fundamental fitness goals (Damasio, 2009). In immediate terms, this means that perceived environmental stimuli are assigned affective value to guide behavioural responses. Episodic foresight, however, enables the temporally extended ascription of value to imagined potential future occurrences, as well (W. Lin, Horner, Bisby, & Burgess, 2015; Suddendorf & Busby, 2005). In other words, humans can determine whether or not a future possibility is good or bad long in advance of its occurrence by the way it makes us feel when we imagine it. Thus, anticipated emotional reactions are commonly evoked in the process of planning appropriate action and making decisions (Baumeister, Vohs, DeWall, & Zhang, 2007; Berns et al., 2007; D. T. Gilbert & Wilson, 2007; Mellers & McGraw, 2001; Rick & Loewenstein, 2008). Imagining a valenced stimulus is sufficient to trigger a cascade of physiological processes that constitute an emotional reaction (Bechara, Damasio, & Damasio, 2000; Damasio, 1994). For example, imagining the experimenter eating one's promised marshmallow feels bad, and this present-moment emotional reaction can be used to infer what one might later feel were one to encounter this event in reality (Gilbert & Wilson, 2007).

It is therefore unsurprising that theoretical accounts of the mechanisms underpinning the effect of episodic foresight on delay discounting have placed emotion centre-stage. Indeed, it has been suggested that emotions caused by the episodic image of a positive future outcome may engage a motivational brake on decisions in the present – serving to counteract present-oriented or impulsive choices from taking precedence (Baumeister & Masicampo, 2010; Boyer, 2008). In essence, the positive affective experience evoked by imagining a future payoff may spur continued patience in the pursuit of this temporally protracted outcome. However, imagining negatively valenced aspects of a future reward possibility, such as a reward being lost, may cause emotions in the present moment as well – serving to spur immediacy instead. Put simply, imagined scenarios can generate affective signals that imbue possible future eventualities with value, with this value information then flexibly guiding present-moment decision-making (Ainslie, 2007; Boyer, 2008; Pezzulo & Rigoli, 2011; Suddendorf & Busby, 2005).

Balancing imagined with actual, perceptible outcomes is a difficult process, especially considering that mental representations become progressively more abstract and less detailed as they move temporally further into the future (D'Argembeau & Van Der Linden, 2004; Trope & Liberman, 2010). Indeed, people are consistently unable (or unwilling) to weight future indulgences as highly as those in the present moment (Irving, 2009), often expressed as beliefs that later pleasures will be less intense than those of today (Kassam, Gilbert, Boston, & Wilson, 2008). This is particularly the case in some highly substance-dependent individuals, who have been shown to heavily underweight potential future consequences (Bechara, 2005; Bechara & Damasio, 2002; Petry, Bickel, & Arnett, 1998). Indeed, in order to balance the value of immediately perceptible versus imagined rewards one must be able to infer how one will feel upon the receipt of a delayed reinforcement. For this reason, some authors have postulated that the same 'theory of mind' mechanisms involved in inferring the thoughts and feelings of other people may be used to simulate the motivational state of one's 'future self', as well as the emotional reaction of this future self to the receipt of delayed rewards (Ersner-Hershfield, Wimmer, & Knutson, 2009; Loewenstein & Schkade, 1999; O'Connell, Christakou, & Chakrabarti, 2015; Suddendorf, 1994).

At a neural level, areas of the prefrontal cortex, particularly the vmPFC and medial rostral prefrontal cortex (mrPFC), as well as the anterior cingulate cortex (ACC), are thought to be involved in the valuation of imagined possibilities by signalling their affective properties (Benoit et al., 2011; Benoit, Szpunar, & Schacter, 2014; W. Lin et al., 2015; Sasse et al., 2015), and consequently may be critical for attributing emotional value to mental representations of future events - even those pertaining to temporally distant long-term goals (D'Argembeau, Xue, Lu, Van der Linden, & Bechara, 2008; Hare, Camerer, & Rangel, 2009). For instance, in one recent fMRI study with healthy participants, enhanced vmPFC activation during imagined primary reward consumption (drinking imaginary fruit juice) was found to positively correlate with lower monetary delay discounting rates in a separate intertemporal choice task (Hakimi & Hare, 2015). In addition, the effect of episodic foresight on delay discounting has been shown to reflect a neural system underpinned by connectivity between such frontal regions involved in decision-making and valuation, and medial temporal regions that are highly active during simulations of future events (Benoit et al., 2014; Peters & Büchel, 2010; Sasse et al., 2015). For example, Sasse et al. (2015) report that functional coupling of the hippocampus with valuation signals in the ACC predicted delay discounting when participants imagined unfamiliar future events timed concurrently with the day of the delayed reward receipt during an intertemporal choice task. Furthermore, recent evidence suggests that the activity of brain regions linked consistently with episodic foresight form a functional network with reward processing regions during self-generated ‘outcome’ simulations of achieving future goals (Gerlach, Spreng, Madore, & Schacter, 2014). Taken together, current evidence suggests that medial temporal lobe structures including the hippocampus play a key role in the valuation of future outcomes because of their involvement in the generation of simulations (see also Johnson, van der Meer, & Redish, 2007). These simulations may then come to be afforded affective relevance and influence decision-making by connectivity with prefrontal cortical regions such as the vmPFC, rmPFC and ACC.

Aside from the ‘anticipated emotions’ discussed above (i.e. predicted emotions in response to a future event), people’s decisions are also influenced both by the emotions they feel in the present moment with reference to a specific future event (‘anticipatory emotions’ like excitement about the upcoming treat), and emotions based on contextual factors or mood (Loewenstein & Lerner, 2003). While the distinction between anticipated and anticipatory emotions is relevant because of their differential content (Barsics, Van der Linden, & D’Argembeau, 2015), and differential association with subsequent behaviour (Carrera, Caballero, & Muñoz, 2012), the distinction is not absolute. As we have seen, anticipated emotions often involve an immediate emotional component that people use to predict their response to the future event if and when it were to occur (Damasio, 1994; D. T. Gilbert & Wilson, 2007).

Nonetheless, the content of one’s imagined future scenarios and one’s mood appear to influence each other (Barsics et al., 2015; Miloyan, Pachana, & Suddendorf, 2014; Quoidbach, Wood, & Hansenne, 2009). This fact has long been recognized: “when we are self-satisfied, we do fondly rehearse all possible rewards for our desert, and when in a fit of self-despair we forebode evil.” (James, 1890). In the context of intertemporal choices made under conditions of episodic future simulation, mood may be an important moderating variable (see also Hirsh, Guindon, Morisano, & Peterson, 2010). Likewise, anticipatory emotions like anxious worrying about the prospect of losing a risky delayed reward may have a complex influence on intertemporal preferences. However, a consideration of the roles of ‘anticipatory’ emotions, and mood has been largely side-lined in theoretical and empirical accounts of the interaction between episodic foresight and intertemporal decision-making (though see Pezzulo & Rigoli, 2011). For example, it remains unclear how positive or negative affect specifically relating to an imagined future scenario may shift intertemporal decision-making *relative to* a similar affective state triggered by one's immediate environment.

### 2.6.2. Likelihood Information

> The ease with which the simulation of a system reaches a particular state is eventually used to judge the propensity of the (real) system to produce that state.
>
> – KAHNEMAN & TVERSKY, 1981, p. 2.

Although humans can explicitly calculate probabilities and rationally compare different likelihoods, most assessments appear to be based on fast and frugal heuristics (Gigerenzer & Goldstein, 1996; Gigerenzer & Todd, 1999). As Kahneman and Tversky (1981) note, mentally simulating a possible future event may provide information about the likelihood of its occurrence. This is in part because people can run through a series of steps in a narrative and thereby estimate the probability of different events transpiring. Thus, the 'ease' with which a mental model of a possible future event comes to mind may act as a heuristic or 'best guess' of the likelihood of it happening. Experimental evidence shows how imagined events that are more easily simulated may come to be estimated as more plausible, probable or likely (Raune, MacLeod, & Holmes, 2005), and that imagining a possible future occurrence can bolster its subjective plausibility. For example, imagining emotional future interpersonal interactions makes them seem more plausible (Szpunar & Schacter, 2013). Similarly, imagining the result of a presidential election or football game makes that outcome seem more likely (Carroll, 1978), and vividly picturing being arrested, contracting a disease, or winning a contest leads these events to be rated as more probable to actually occur (Gregory, Cialdini, & Carpenter, 1982; Sherman, Cialdini, Schwartzman, & Reynolds, 1985).

These modified likelihood perceptions can directly affect intentions, decisions and behaviours. For instance, the repeated simulation of helping behaviours appears to increase intentions to help others (Gaesser & Schacter, 2014), and homeowners who imagine themselves using a cable TV service in the future are more likely to subscribe to such a service when given the opportunity (Gregory et al., 1982). When making decisions in an intertemporal choice situation, this is predicted to manifest as increased preferences for delayed larger rewards after repeated positive outcome simulations. However, it may also lead to more immediacy in decisions after repeatedly imagining negative possibilities.

In each case, this is expected partly as a result of the increased subjective plausibility that repeated simulations incur: for example, repeatedly imagining a future reward being lost may increase the subjectively perceived likelihood of this eventuality. Subsequently, the perceived high likelihood of losing the future reward might lead to discounting of that reward in favour of more immediate and certain options. Indeed, several studies have shown that anxious individuals, a group that is prone to repetitive negative future-oriented thinking and a reduced tolerance of risk and uncertainty (Miloyan, Pachana, et al., 2014), more steeply discount delayed rewards (Luhmann, Ishida, & Hajcak, 2011; Rounds, Beck, & Grant, 2007; Worthy et al., 2014). However, given that the content of prospective imagery amongst clinically anxious people is often highly negatively-valenced, the respective importance of repeated simulation (likelihood) and emotionality in this context remains unclear (see Wu, Szpunar, Godovich, Schacter, & Hofmann, 2015).

Figure 2.1 illustrates how episodic foresight may feed back information about the affective relevance and likelihood of future rewards to adjust decision-making mechanisms and preferences in intertemporal choice situations. Note that these two sources of information probably interact in a number of important ways (Buechel, Zhang, Morewedge, & Vosgerau, 2014; Szpunar & Schacter, 2013). For example, Szpunar and Schacter (2013) report that while imagining potential future interpersonal experiences increases the subjective plausibility of these possibilities, this is only the case for positively and negatively emotional events, not neutral ones (see also Wu et al., 2015). However, the precise manner in which affective and likelihood information about a simulated future event interact so as to influence intertemporal preferences, for example in terms of their respective weighting by decision-making mechanisms, remains unknown.

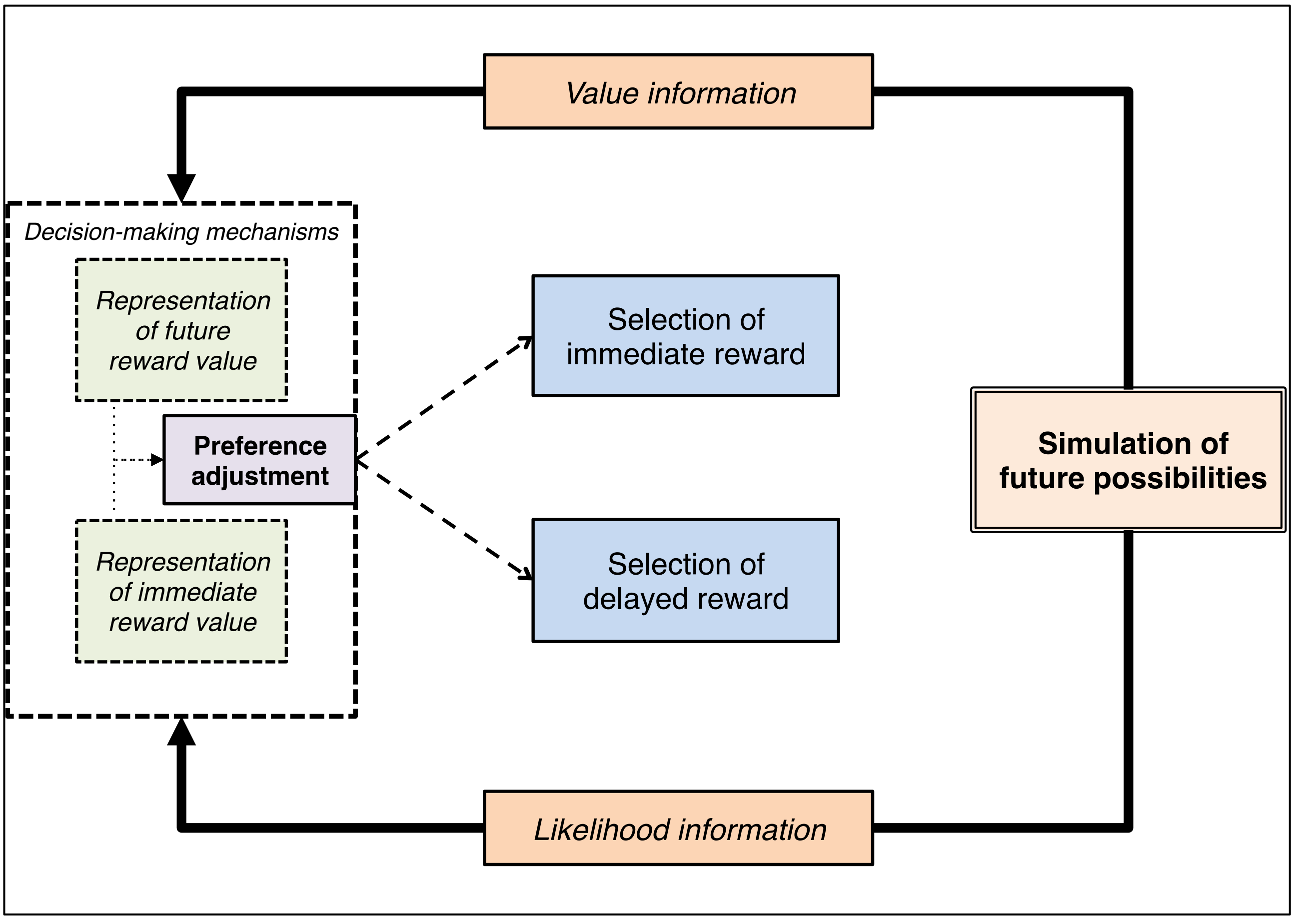


*Figure 2.1.* Simulations of future reward outcomes and contexts feed back value and likelihood information into decision-making mechanisms. These mechanisms are responsible for executing the behavioural selection of immediate or delayed rewards, and preferences for these rewards may shift differentially depending on what is simulated.

### 2.7. The role of systematic biases in foresight

Despite the ubiquity of human attempts to model or represent future possibilities, such predictions are often wrong in innumerable ways. In part, this is because the future is inherently uncertain and people can only make approximations of what may unfold. However, humans have also been shown to exhibit systematic *biases* in their forecasts that may have some ultimate benefits. Firstly, people tend to consistently overestimate the intensity and duration of their emotional responses to both positive and negative future events (T. D. Wilson & Gilbert, 2005a, 2005b). This so-called *impact bias* is pervasive, and has been found to apply to predictions about events ranging from sporting victories to limb amputations (Halpern & Arnold, 2008; T. D. Wilson & Gilbert, 2005a). Secondly, people have a consistent tendency to overestimate the likelihood of positive events and underestimate the likelihood of negative events occurring to them (Sharot, Korn, & Dolan, 2011; Taylor & Brown, 1988; Weinstein, 1980). This *optimism bias* is also widespread, occurring when people make predictions about the longevity and outcomes of their relationships (Baker & Emery, 1993), their estimated life expectancy (Puri & Robinson, 2007), and the promise of their business initiatives (Lovallo & Kahneman, 2003).

These biases may serve functional roles in the orchestration of flexible intertemporal decision-making (see also McKay & Dennett, 2009). Attempting to wait for a desirable future reward in the face of competing temptations is difficult, requiring patience and self-control. Overestimating both the likelihood and positive emotional significance of receiving a desired future reward may thereby serve to motivate behaviour in its pursuit (Miloyan & Suddendorf, 2015; Morewedge & Buechel, 2013). In a similar vein, people strategically (though probably not consciously) overestimate their likelihood of goal success when they expect to encounter more obstacles in the pursuit of that goal (Y. Zhang & Fishbach, 2010). Furthermore, the negative emotional impact of an imagined future threat may be wisely exaggerated to incentivize its avoidance (Miloyan & Suddendorf, 2015), according with the 'smoke detector' principle that it is better to over respond to a potential threat than to not respond to a real one (Marks & Nesse, 1994). The impact bias may therefore have adaptive evolutionary significance insofar as it "transforms the trivial into the consequential" (Hoerger, Quirk, Lucas, & Carr, 2010, p. 10), motivating appropriate decisions in light of temporally protracted possible events (Miloyan & Suddendorf, 2015; Morewedge & Buechel, 2013). The decision of whether to indulge in an immediate reward or wait for a future one that is in opposition to it may draw on the exaggerated glee or despair one imagines they will feel if that future reward *does* or *does not* materialize, respectively.

### 2.8. The flexible allocation of self-control as a function of episodic foresight

As already noted, a capacity for self-control in the face of competing temptations is widely considered to be a fundamental and critical human capacity (Baumeister & Tierney, 2011; A. Diamond, 2013; Herrmann et al., 2014; Tangney, Baumeister, & Boone, 2004; Vohs & Baumeister, 2011). Deciding to indulge in immediate rewards in favour of larger but delayed ones has often been considered as resulting from a lack of self-control (Logue, 1988; Mazur & Logue, 1978; Rachlin, 1974), or to reflect a reduced capacity for self-regulation in the face of impulses (Tangney et al., 2004). However, although the capacity to delay gratification has been consistently linked to positive life outcomes (Mischel et al., 2011, 1989; Schlam et al., 2013; Shoda et al., 1990), delaying gratification is only adaptive in certain environmental circumstances (Fantino, 1995; Fawcett et al., 2012; Logue, 1988).

Furthermore, for the delay of gratification to be functional, it must eventually cease: one cannot wait indefinitely for food, for instance, as that would lead to starvation whilst "waiting for the windfall" (Santos & Rosati, 2015, p. 337). This extreme example illustrates the more general point that, eventually, a decision-maker must cease exercising self-control and capitalize on an opportunity. In humans, aspects of higher trait impulsivity are related to positive social and occupational outcomes (Gullo & Dawe, 2008), especially in areas that may benefit from a propensity to capitalize on opportunities such as in entrepreneurial endeavours (Stewart  Jr. & Roth, 2001). Simulating different aspects of a future reward and its context can aid assessment of whether or not to delay gratification in its pursuit. In situations where a future reward is imagined as particularly valuable and likely, one may be best off allocating self-regulatory resources to inhibit responses to other temptations en route to this goal (Baumeister & Masicampo, 2010; Boyer, 2008). However, in imagining a future reward as less valuable or likely, one may be better off reserving those self-regulatory resources. This is consistent with views of self-control as a resource that partially depletes with use and is selectively allocated (Baumeister, 2014; Baumeister, Bratslavsky, Muraven, & Tice, 1998), as engaging in episodic foresight may provide information about whether or not to allocate this limited resource in a particular circumstance.

At least two aspects of the intertemporal choice and delayed gratification research paradigms may have obfuscated the role of episodic foresight we have outlined. Firstly, both paradigms are usually posed as a choice between two rewards that are certain to materialize (though see Reynolds & Schiffbauer, 2004). The real world, at least the ancient ecological context in which decision-rules evolved, does not tend to present such clear-cut choices. Instead, different degrees of uncertainty are an inherent property of natural future outcomes (Loewenstein et al., 2003). For instance, there is always some intrinsic uncertainty about food rewards until they are inside one's mouth. More distant future outcomes are obscured, intangible, and remain uncertain when viewed through the fog of time (Rick & Loewenstein, 2008). Thus, intertemporal choices are not just choices between reward value and time, but also between different perceived probabilities. It remains to be seen if tasks in which the certainty of acquiring delayed rewards is systematically manipulated are more sensitive to individual differences in episodic foresight. For instance, when high uncertainty is built *explicitly* in to future rewards, one possibility is that people who more vividly imagine negative future possibilities may be more prone to shift their preferences towards immediate rewards, on account of imagining the eventuality of future loss. To test this hypothesis, cues to engage in episodic foresight could be presented during intertemporal choices where future rewards vary explicitly in their likelihood, such as in a combined delay and 'probability discounting' paradigm or an 'experiential discounting task' (see McKerchar & Renda, 2012; Reynolds & Schiffbauer, 2004).

Secondly, there is an important opportunity cost associated with some varieties of patient waiting that is not usually modelled in laboratory paradigms. In natural environments, if an animal spends time attempting to access one reward, opportunities to access other rewards are diminished. For example, the time taken to crack open a shell to retrieve the food reward within results in reduced opportunities to engage in the pursuit and acquisition of other food sources (Stevens & Stephens, 2008). This opportunity cost may be factored into intertemporal decision-making mechanisms in animals and may be one of the key reasons why delayed rewards become less subjectively valuable over time, whether or not the animal knows this (Fawcett et al., 2012; Stephens, 2002). However, the explicit and episodic simulation of this opportunity cost may further influence human decision-making during intertemporal choice. Choosing a delayed reward in most laboratory intertemporal choice tasks does not forego other reward-seeking opportunities. If it did, however, we predict that when people are cued to engage in episodic foresight of this opportunity cost they may be more inclined towards immediacy than individuals not engaging in episodic thinking. In other words, explicitly simulating the other rewards one *could* be pursuing instead of waiting may also produce a flexible modification of preferences towards smaller but sooner rewards.

In this section we have suggested that episodic foresight may act as a mechanism for determining the best allocation of self-regulatory or 'self-control' resources. By imagining a possible future reward or the context of its receipt, a decision-maker can better determine whether or not it is worth being 'patient' and restricting access to other indulgences in its pursuit. Furthermore, we have outlined how the lack of (i) uncertainty and (ii) an explicit opportunity cost in laboratory studies of intertemporal choice may have somewhat obscured the flexibility afforded by episodic foresight over intertemporal preferences.

**2.9. Clinical considerations**

A wide body of literature has now documented that episodic foresight is impaired in certain populations. Older adults show deficits in episodic foresight (Lyons, Henry, Rendell, Corballis, & Suddendorf, 2014), most likely as a result of cortical deterioration in the regions thought to support this capacity (Schacter, Gaesser, & Addis, 2013). Experimental findings indicate that older adults have greater difficulty imagining the future rather than imagining experiences *per se* (Rendell et al., 2012). Episodic foresight appears to even more impaired in age-related neurodegenerative disorders, such as Alzheimer's disease (Addis, Sacchetti, Ally, Budson, & Schacter, 2009; Irish & Piolino, 2016), in which the capacity to imagine the future may deteriorate alongside the capacity to evoke episodic memories. We might predict individuals suffering from a reduced capacity to imagine the future due to aging or age-related neurodegenerative disease to derive less flexibility over intertemporal choices when cued to engage in episodic foresight.

There are also qualitative differences in episodic foresight amongst clinical subgroups that retain the ability to imagine the future, with regards to the detail and content of imagined episodes. For instance, one recent study showed that long-term opiate users were selectively impaired in their ability to vividly imagine details of the future, without any associated deficits in episodic memory (Mercuri et al., 2014). A similar reduction in the richness of episodic simulations, alongside a reduction in activity of corresponding brain regions, has been reported in individuals with depression (Hach, Tippett, & Addis, 2014). This latter group has also been shown to be less likely to generate positive future events in a fluency paradigm relative to controls (MacLeod & Byrne, 1996). Selective generation of particular content is also found in anxious individuals, who are more likely to imagine negative or threat-related affective content, but not fewer positive experiences than controls (Miloyan, Pachana, et al., 2014). Interestingly, anxiety may also be associated with heightened generality of thought content (i.e. more semantic than episodic details). Individuals with PTSD, for instance, have been shown to generate highly general content when imagining the future (A. D. Brown, Addis, et al., 2013; A. D. Brown, Root, et al., 2013).

The use of episodic foresight to flexibly adjust intertemporal decision-making may be particularly heterogeneous in the populations outlined above, though the degree to which this is true remains largely unknown. For example, we might expect people with higher trait anxiety or depression to more readily shift their preferences towards immediate rewards when imagining the future during an intertemporal choice situation, considering that these individuals are prone to repeatedly generating negatively valenced future thoughts (Miloyan, Pachana, et al., 2014; Miloyan & Suddendorf, 2015; Roepke & Seligman, 2015). We might also expect both individuals with PTSD and depression, who typically report overgeneralized future thinking with reduced episodic specificity (A. D.

Brown, Addis, et al., 2013; A. D. Brown, Root, et al., 2013; Hach et al., 2014), to derive less flexible modification of discounting considering they may be unable to generate the detailed episodic imagery usually associated with these effects (Peters & Büchel, 2010). Patients with bilateral amygdala lesions who demonstrate a marked lack of anxiety (Bach, Hurlemann, & Dolan, 2015; Feinstein, Adolphs, Damasio, & Tranel, 2011) might however also be predicted to receive very little modification of discounting from the imagination of a negative future event (e.g. increased immediacy after ruminating on the loss of a future reward), because of an inability to integrate affective anxiety appraisals with simulated mental images.

### 2.10. Future directions and conclusions

A number of additional questions and directions for future research remain about the role of episodic foresight in intertemporal choice. For instance, it will be important to tease apart the relative contributions of episodic and semantic forms of prospection in modifying intertemporal choices. This is underscored by a recent study by Kwan and colleagues (2015) who found that people with hippocampal amnesia who have an impaired ability to imagine the future may still derive some flexible modification of discounting when cued to engage in episodic foresight, perhaps as a function of intact semantic or implicit prospective mechanisms. In what ways and to what extent does episodic foresight modify choices over and above semantic priming of the future? Similarly, what is the role of vivid mental simulation of future outcomes relative to a verbal or semantic ‘consideration’ of the future that does not involve engaging in fully-fledged episodic simulation? (Strathman, Gleicher, Boninger, & Edwards, 1994; Zimbardo, Keough, & Boyd, 1997). Studies of intertemporal choice in animals, children, and in hippocampal lesion patients may prove to be fruitful avenues for delineating the relative contribution of different prospective mechanisms to future-oriented behaviour (Cheke, Thom, & Clayton, 2011; Osvath & Martin-Ordas, 2014; Palombo, Keane, & Verfaellie, 2015; Thom & Clayton, 2015).

Furthermore, the role of episodic foresight has yet to be explored in other intertemporal choice paradigms such as the accumulation and exchange type tasks used in much of the animal literature, in choices between immediate and delayed punishments (rather than rewards), or in a diverse range of other contexts such as when multiple future rewards are on offer. Because very young children are often extremely steep delay discounters, it would also be relevant to explore the developmental trajectory by which episodic foresight becomes an avenue for adjusting intertemporal preferences (Bar, 2010).

In general, between 3 and 4 years of age children become increasingly capable of delaying their gratification in pursuit of delayed rewards (Atance & Jackson, 2009; Hongwanishkul, Happaney, Lee, & Zelazo, 2005; Imuta, Hayne, & Scarf, 2014). Furthermore, some recent evidence suggests that between 3.5 and 4.5 years of age, children begin to *adapt* their intertemporal choices and saving behaviours based on changing risk contingencies (W. S. C. Lee & Carlson, 2015). Interestingly, this is around the same time that children appear to acquire the main cognitive components required to construct mental scenarios of future events and embed them into larger narratives (Suddendorf & Redshaw, 2013). As such, future research should explore the specific relationship between the development of episodic foresight and the capacity to flexibly adjust intertemporal preferences in early childhood (Garon, Longard, Bryson, & Moore, 2012; Lemmon & Moore, 2007). Finally, much remains to be determined about the role of variables such as working memory capacity: for instance, how will episodic foresight modify discounting rates under conditions of high cognitive load, given that working memory capacity appears crucial in the effect of episodic foresight on delay discounting (H. Lin & Epstein, 2014)?

Although episodic foresight may not be required for some short-term adaptive intertemporal choices, we have argued that it provides critical flexibility in future-directed decision-making. Imagining future events and embedding them into larger narratives enables humans to compare diverse possibilities and probabilities, to derive prudent plans of action. While the role of episodic foresight in facilitating self-control in pursuit of long-term goals has previously been emphasized as critical, we have here pointed out that it may also result in a shift in preferences towards immediate rewards. In light of a positive imagined future, preferences may shift towards desired long-term goals. However, when a negatively valenced future is anticipated, the acquisition and consumption of immediately available rewards may be prioritized because future ones are expected to be less likely to materialize. The most adaptive option in intertemporal choice situations can change in response to assessments of the value and likelihood of possible future rewards brought about by simulating the future. In this way, episodic foresight provides humans with adaptive flexibility when faced with intertemporal choice situations in a manner that extends the fundamental evolutionary logic of delay discounting and delayed gratification.

## Chapter Three. The influence of episodic foresight on delay discounting and demand for alcohol

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### Preface and details of contribution to authorship:

In this chapter I present the results of an experimental study into the effects of cued episodic foresight on impulsivity in the domains of intertemporal decision-making and alcohol demand. The chapter explores an idea from the model presented in the previous chapter: that imagining a positive future can reduce delay discounting and other domains of choice with an intertemporal trade-off. I conceived the study and designed the experiment in collaboration with Matthew J. Gullo. I collected the data and performed the analyses with guidance from Matthew J. Gullo. I wrote the first draft and finalized the paper after important revisions from Matthew J. Gullo.

## Abstract

Background: There is a near-universal tendency to discount the value of delayed rewards relative to those available in the here and now. The rate at which future rewards become devalued over time, delay discounting, is an important individual difference variable related to impulsivity and is elevated in externalising disorders, including alcohol use disorders. Recent research suggests that vividly imagining personally relevant future events (episodic foresight) during an intertemporal choice task can attenuate the rate at which delayed rewards are discounted. Objectives: The present study sought to extend these findings by examining the effect of episodic foresight on both delay discounting and alcohol-related decision-making. Methods: Forty-eight college students were administered both modified intertemporal choice and hypothetical alcohol purchase tasks during which personally relevant episodic future event cues or control imagery cues were presented. Results: Engaging in episodic foresight reduced both the rate at which delayed monetary rewards were discounted and initial alcohol demand intensity (but not other demand indices) relative to control imagery. Conclusions: Findings suggest that the attenuating effect of episodic foresight on impulsivity may be limited to particular aspects of impulsive choice.

## 3.1. Introduction

Making adaptive decisions often requires a decision-maker to suppress impulses toward immediate gratification in the pursuit of long-term goals. Difficulty doing so has been conceptualized as a key feature of impulsivity, and is characteristic of many behavioural disorders in which immediate gratification becomes highly prioritized over the pursuit of longer-term reinforcement (Bickel & Marsch, 2001; Gullo & Potenza, 2014; MacKillop et al., 2011). Thus, while there is a near-universal tendency to discount the value of future rewards relative to those in the here-and-now, individuals with substance use disorders, pathological gambling, obesity, and other risky health behaviours have been consistently found to more rapidly devalue rewards that are delayed in their receipt than healthy controls (Bickel & Marsch, 2001; Dixon et al., 2003; Story et al., 2014). Thus, responses to *intertemporal choices* between rewards available immediately and those available only after a delay can act as a 'behavioural marker' of addiction-relevant outcomes including the severity, and risk of developing, dependence (for review see Bickel, Koffarnus, Moody, & Wilson, 2014).

Individual differences in discounting rate have been tied to a number of factors, including genetic heritability and early life developmental experiences (Anokhin, Golosheykin, Grant, & Heath, 2011; Mauro & Harris, 2000; Odum, 2011; Peters & Büchel, 2011). However, the rate at which future rewards are devalued can also vary widely *within* individuals, as a function of the perceived certainty of a future reward, the framing of the choice question, current affect, alongside other situational or biological variables (for review see Lempert & Phelps, 2015). One critical set of psychological variables associated with variation in the discounting rate is the manner in which individuals mentally represent or imagine future rewards and the context of their receipt (Bulley, Henry, & Suddendorf, 2016).

A number of recent experimental studies suggest that imagining the future, so-called *episodic foresight* (Suddendorf & Corballis, 1997, 2007) or *episodic future thinking* (Atance & O'Neill, 2001), can reduce the rate at which future rewards are discounted in the process of making intertemporal choices. In general, these studies have provided participants with modified intertemporal choice tasks (ICTs) in which a personally relevant future event cue is provided alongside the choice question (Benoit et al., 2011; Daniel et al., 2015, 2013a, 2013b; Kwan, Craver, et al., 2015; H. Lin & Epstein, 2014; Liu et al., 2013; Palombo et al., 2014; Peters & Büchel, 2010). For example, in Peters and Büchel (2010), participants indicated their preference for either 20€ now, or 35€ in 45 days, while in some trials being simultaneously cued with an actual event they had planned in around 45 days time. In the episodic cue condition, preferences shifted towards longer-term rewards, and the strength of this effect was associated with individual differences in the vividness of the mental imagery about the episodic future event.

The effect of episodic foresight has been shown to extend to real-world behavioural indices of impulsive choice. When tempted with unrestricted access to immediately gratifying, densely caloric food, both obese women and children consumed less if concurrently imagining personally relevant future events (Daniel et al., 2015, 2013b). This effect of episodic foresight on impulsive eating has also recently been demonstrated in college women, such that food-related episodic future thinking led to more restricted consumption of freely and immediately available snacks (Dassen et al., 2016), and in a sample of obese or overweight women in a real-world food-court experiment (O'Neill et al., 2015).

A large body of evidence suggests that problematic alcohol users tend to show steeper discounting rates than individuals who use alcohol at more moderate or less risky levels (MacKillop et al., 2011; Petry, 2001). While individuals may not be explicitly deciding between payoffs at different times when they choose whether or not to eat unhealthy foods or drink alcohol, there is commonality between the type of decision-processes tapped by the ICT, and the processes employed in such health-related consumption decisions (Yi, Mitchell, & Bickel, 2010). In both cases, the options exist to make either (i) a decision prioritizing immediate gratification (e.g. pleasure) or (ii) a decision that prioritizes longer-term gains (e.g. health). Purchase demand for alcohol is one measure than can be employed to investigate this decision-process, and is predictive of alcohol consumption (Dennhardt, Yurasek, & Murphy, 2015; Murphy et al., 2015) as well as problematic alcohol-related behaviours such as driving after drinking (Teeters, Pickover, Dennhardt, Martens, & Murphy, 2014).

Demand for alcohol can be directly assessed with hypothetical 'alcohol purchase tasks' (APTs) that ask participants to indicate their willingness to purchase hypothetical drinks at increasing costs (MacKillop et al., 2009, 2010; MacKillop & Murphy, 2007; Murphy, MacKillop, Skidmore, & Pederson, 2009). There is generally good correspondence between hypothetical tasks of this nature and tasks in which access to alcohol is provided (Amlung, Acker, Stojek, Murphy, & MacKillop, 2012). As such, given recent studies showing that episodic foresight can reduce not only delay discounting but also 'impulsive' eating, in the current study we aimed to explore the effect of episodic foresight on both standard monetary intertemporal choice, as well as alcohol demand using a hypothetical APT. Firstly, we hypothesized that engaging in episodic foresight during the ICT would attenuate the rate at which future rewards were subjectively devalued over time. Secondly, we hypothesized that engaging in episodic foresight would reduce 'impulsive' alcohol demand on the hypothetical APT.

## 3.2. Method

### 3.2.1. Participants

Fifty-two undergraduate students participated in the study for course credit. The study was approved by the relevant university human research ethics committee. Four (7.7%) participants were excluded because they did not attend both experimental sessions. This left a final sample of 48 participants (33 females, 68.8%). The mean age of the sample was 20.67 years (*SD* = 5.36).

### 3.2.2. Design and Procedure

Participants attended two sessions timed roughly one week apart, in a within-participants design modelled after Daniel, Stanton & Epstein (2013a). In both sessions, participants completed a modified ICT, in which they made a series of choices between immediate (smaller) or delayed (larger) rewards available at five future time-points, and a hypothetical APT, in which they indicated how many drinks they would consume at various price intervals. During both tasks, participants were presented with cues to engage in either (i) episodic foresight or (ii) control imagery before each decision point, with the order of this manipulation counterbalanced between sessions.

The episodic or control cues were generated at the start of the respective session, and were drawn from either (i) personally relevant events that participants listed they were looking forward to in the future (episodic), or (ii) events from a story with vivid imagery that they were instructed to read (control). Participants also completed the Alcohol Use Disorders Identification Test (AUDIT). At the end of each session, participants rated dimensions of their mental imagery during the tasks. Demographic information was collected at the start of the first session, and participants underwent a funnel debriefing procedure at the end of the second session.

### 3.2.3. Manipulations

***3.2.3.1. Episodic Foresight.*** At the start of the episodic foresight session, participants were asked to imagine and list personally relevant future events that they were "looking forward to" over the next year. Specifically, they were asked to provide two events for each of the time delays corresponding to the reward delays in the ICT, and to rate the vividness, positive emotionality, and personal relevance of these events on a scale from 1 (*not at all*) to 6 (*very*). For each time point (today, two-days, 30-days, 180-days, and 365-days), the events with the highest average rating across these scales were selected as cues for the episodic foresight manipulation. These episodic cues were inserted into the code of the computerized ICT, to be presented before each decision in a manner that synchronized the temporal distance to both the possible future event and the delayed reward. For example, participants would be presented with a cue to imagine an event they were looking forward to in around 180 days before making a choice about a reward that was delayed by that same amount of time. The episodic cues were also presented in the APT, though because this task lacks a temporal component, the cues appeared before each decision in an arbitrary order.

***3.2.3.2. Control imagery.*** At the start of the control imagery session, participants read the first two chapters of "Pinocchio", which contains many highly vivid events (e.g. "Geppetto turned the colour of a red pepper"). The story was split into five pages, and participants were instructed to list two events from each page that they enjoyed and to rate the vividness, positive emotionality, and personal relevance of these events on a scale from 1 (*not at all*) to 6 (*very*). The events with the highest average ratings were selected as cues for the control imagery manipulation. Because the story events were fictitious rather than specific temporal events, the control cues were inserted into the ICT and APT in an arbitrary order. This control imagery task was based on a previous study by Daniel, Stanton and Epstein (2013a) and meant that participants were engaging in mental imagery (and thereby constructing a mental scenario as per the episodic condition), but that these simulations differed from the episodic foresight imagery inasmuch as they were (i) fictitious (ii) not prospective, (iii) not personally relevant events.

### 3.2.4. Measures

***3.2.4.1. Intertemporal Choice Task (ICT).*** Participants were presented with a series of computerised choices between a small, immediate amount of money (e.g. $2) and a larger, consistent amount ($10) that was variably delayed in its receipt by 0, 2, 30, 180 or 365 days (J. B. Richards et al., 1999). Participants were instructed to answer as if they were really going to receive the rewards after the designated delay. A screen displayed the choice question and two response buttons, an episodic or control event cue in bold red lettering, and a prompt instructing the participant to imagine the event. Imagination in the task was self-paced. Participants were instructed before the task that when an event cue was presented they should take a few moments to vividly imagine the event, including as many sensory and emotional details as possible, before making their decision. The instruction to explicitly imagine the events differed from one previous study in which participants were merely cued with future events (Peters & Büchel, 2010), but closely resembled other studies that have given similarly explicit instructions (Daniel et al., 2013b; H. Lin & Epstein, 2014).

Participants were also told they did not need to imagine spending the money during the event, meaning the imagination component of the task was ostensibly unrelated to the decision-making component. A titrating adjusting-amount procedure converged on the 'indifference point' for each of the delays at which point the subjective value of the immediate (smaller) and future (larger) reward was indistinguishable. The program was set to terminate after converging (or making a substantial number of attempts to converge) on an indifference point for each delay (for full details of the discounting program see J.B. Richards et al., 1999). The indifference points for each delay produced by the ICT were used to generate area under the indifference curve (AUC) values, with higher AUC values representing lower delay discounting. For more information on this calculation see (Myerson, Green, & Warusawitharana, 2001; Reed, Kaplan, & Brewer, 2012). Because participants completed two intertemporal choice tasks (once with episodic cues, once with control cues), we calculated AUC values separately for both iterations of the ICT.

***3.2.4.2. Alcohol Purchase Task (APT).*** Alcohol demand was assessed with a state-oriented hypothetical APT modelled after MacKillop et al (2010), which requires participants to list how many drinks they would purchase and consume at various prices. The APT instructions specified that drinks had to be consumed, not stockpiled, and that 'a drink' was defined as standard sized beer, wine, or shot of liquor (straight or mixed). Participants were presented with nineteen price intervals, one by one, alongside a text-box wherein they entered the number of drinks they would buy at that price. The price intervals were zero (free), 1¢, 5¢, 13¢, 25¢, 50¢, $1, $2, $3, $4, $5, $6, $11, $35, $70, $140, $280, $560, and $1120. The approximately doubling interval spacing is common in demand tasks and is based on a progressive-ratio operant schedule (Jacobs & Bickel, 1999; MacKillop et al., 2010). Before each price interval screen a separate display appeared with an event cue (episodic or control), alongside instructions asking the participant to take a few moments to imagine this event. Once participants had imagined the event for a few moments, they were free to respond.

The APT produces five 'demand indices' that reflect different aspects of alcohol purchasing behaviour (MacKillop et al., 2009; Murphy & MacKillop, 2006). *Intensity* of demand is the number of drinks requested at zero cost (when drinks are free). *Breakpoint* is the price at which the requested drinks equal zero (the price that first suppresses consumption to zero demand). *'$O_{max}$'* is the highest observed *expenditure* on alcohol across the price intervals (the most amount of money spent at any one price). *'$P_{max}$'* is the price at which $O_{max}$ occurs (i.e. the price point at which the most money is spent on drinks). *Elasticity,* which is derived from demand-curve modelling, indicates the rate of decrease in consumption as a function of cost (Murphy et al., 2009).

***3.2.4.3. Alcohol use.*** Alcohol use patterns were assessed with the AUDIT, which is a 10-item self-report questionnaire with questions about drinking amount, frequency, dependence, and drinking-related problems (Saunders, Aasland, Babor, de la Fuente, & Grant, 1993). The AUDIT is a screening instrument for problematic drinking patterns. It has good internal reliability and test–retest reliability across various populations (e.g., university students, emergency room patients) (Daeppen, Yersin, Landry, Pécoud, & Decrey, 2000; Dawe, Loxton, Kavanagh, & Mattick, 2002). Scores on the AUDIT correlate with other measures of risky or harmful drinking (O'Hare & Sherrer, 1999), and can effectively classify dependent and non-dependent drinkers (Saunders et al., 1993).

***3.2.4.4. Cue ratings.*** At the end of each session, participants rated the vividness, positive emotionality, and personal relevance of each event cue on scale from 1 (*not at all*) to 6 (*very*). Participants also rated how frequently each event cue evoked their imagination during the tasks, from 1 (*never*) to 6 (*every time*).

## 3.3. Results

### 3.3.1. Drinking behaviours of the sample

The mean AUDIT score was 5.73, with 14 (29%) participants scoring above the 8+ cut-off for hazardous drinking specified by Saunders et al. (1993). When asked how often they have a drink containing alcohol, approximately 17% of the sample responded with 'never', 38% with 'monthly or less', 31% with '2-4 times a month', 13% with '2-3 times a week' and 2% with '4 or more times a week'. When asked how many standard drinks they have on a typical day when they are drinking, approximately 56% responded with '1 or 2', 20% with '3 or 4', 20% with '5 or 6', none with '7 to 9' and 2% with '10 or more'.

### 3.3.2. Cue ratings

One participant was missing data from the control session cue-rating questionnaire and as such these data were estimated with Expectation Maximisation (Dempster, Laird, & Rubin, 1977). Paired-samples t-tests revealed that participants rated the personal relevance of the episodic imagery significantly higher ($M$ = 5.34, $SD$ = 0.54) than the personal relevance of control imagery (*M* = 3.06, *SD* = 1.2), *t* (47) = 12.14, p < 0.001, and that participants rated the positive emotionality of episodic imagery (*M* = 5.39, *SD* = 0.52) significantly higher than control imagery (*M* = 3.89 *SD* = 0.92), *t* (47) = 9.78, p < 0.001. As in previous studies (Daniel et al., 2013a, 2013b), a general 'imagery' score was calculated by averaging the self-reported vividness and frequency of imagery during the tasks. Overall, participants rated the combined frequency and vividness of their imagery significantly higher in the episodic condition (*M* = 5.06, *SD* = 0.54) than in the control condition (*M* = 4.61, *SD* = 0.84), *t* (47) = 3.92, *p* < 0.001. As per Daniel et al., (2013a, 2013b), the difference between the imagery in the two conditions was entered as a covariate in subsequent analyses. This meant that observed effects were selective to the differences between the episodic and control tasks such as the personal relevance and future-directedness of the events, rather than reflecting a mere difference in frequency and vividness of imagery evoked in each of the conditions.

**3.3.3. Episodic foresight during intertemporal choice**

Some participants lacked sufficient data on the ICT due to repeatedly inconsistent responses in either the control (n = 7; 15%) or episodic (n = 4, 8%) session. In each case, the program's adjusting-amount procedure was unable to converge on an indifference point for one of the delays after a number of convergence attempts. Response inconsistency is not uncommon in studies employing ICTs (Isen, Sparks, & Iacono, 2014; Jonhson & Bickel, 2008; Olson, Hooper, Collins, & Luciana, 2007). Because of the repeated measures design, the participants with incomplete data from either of the two ICTs were excluded from the subsequent discounting analyses, in line with previous studies using the same procedure (e.g. Isen et al., 2014). The excluded cases did not differ significantly in terms of gender, general imagery scores, AUC values, or AUDIT scores (*ps* > 0.05).

A one way repeated measures ANCOVA was run with condition (episodic vs. control) as the within-subjects factor and AUC as the outcome, controlling for imagery differences. Gender was also included as a covariate because of previous studies suggesting a relationship between gender, delay discounting and episodic thinking (Seinstra, Grzymek, & Kalenscher, 2015). This ANCOVA revealed a significant difference in discounting between the episodic and control conditions, *F* (1, 34) = 8.42, *p* = 0.006, $\eta_p^2$ = .198, such that engaging in episodic foresight increased AUC values (*M* = 0.71, *SD* = 0.26) compared to control imagery (*M* = 0.54 *SD* = 0.30). Because higher AUC values represent less steep discounting of future rewards, this suggests that episodic foresight reduced impulsivity on the task relative to control imagery (see Figure 3.1). No significant interactions emerged between condition and any covariate (ps > 0.05), and as such the assumption of homogeneity of regression was not violated.

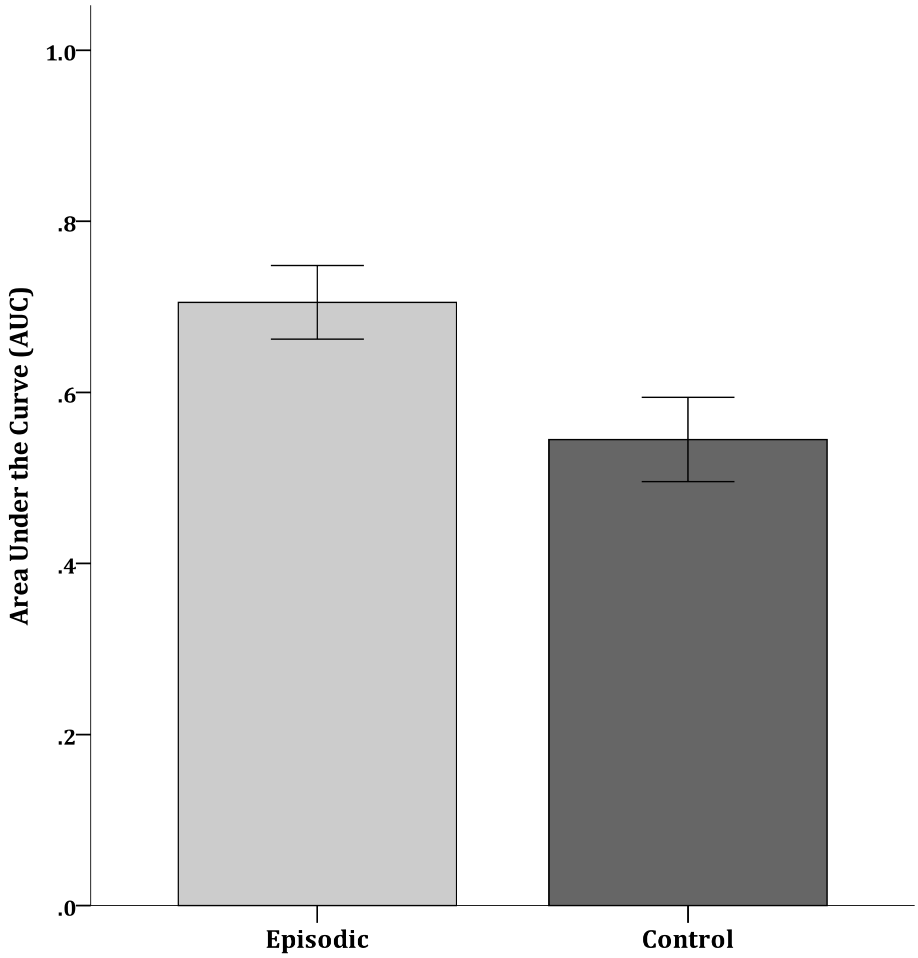


*Figure 3.1.* Area under the curve values in the episodic and control imagery conditions. N = 37, **p < 0.01. Error bars represent ±1 SEM.

### 3.3.4. Episodic foresight during Alcohol Purchase Task

Two participants did not complete the APT because they indicated they would abstain from drinks regardless of circumstances (they were non-drinkers), so these participants were removed from subsequent APT analyses. We did not remove the participants who indicated they typically did not drink on the AUDIT, because this response does not exclude the possibility of non-zero demand in the APT, which contains price-points for drinks that are free, or of very low cost. Data were initially screened as per previous studies utilizing an APT (Amlung & Mackillop, 2014; Amlung & MacKillop, 2012;

MacKillop et al., 2010). We were tolerant of violations of the assumptions about the directional change in consumption across price increments (e.g. bounce/ preference reversals) because in both iterations of the task participants underwent an imagination manipulation whose influence on choice patterns or consistency could not be predicted (see Stein et al., 2015). Four participants were excluded for non-consumption (zero demand) on the APT. Raw demand data were examined for outliers with a criterion of $Z = 4$ to retain maximum data (as per MacKillop, 2010). A small number of high-magnitude outliers were detected in the raw demand data, all of which were recoded to the next highest non-outlying value. After screening the price-level data and computing the behavioural economic demand indices, the demand indices were also examined for outliers with a standard criterion of $Z > 3.29$. These demand index outliers were recoded as one unit higher than the next highest value (Tabachnick & Fidell, 2007). The distributions of all demand indices were examined for normality with histogram plots, which indicated that $O_{max}$, $P_{max}$, intensity and breakpoint were positively skewed. These indices were therefore subjected to square-root transformations, which greatly improved the skewness of all distributions. As per Amlung and Mackillop (2012), elasticity of demand was derived by using a non-linear exponential demand curve equation from Hursh and Silberberg (2008), and was subsequently subjected to a logarithmic transformation on account of its skewness. Because actual alcohol use behaviours have been found to be associated with APT responses (Amlung et al., 2012), analyses of the demand indices included AUDIT scores as a covariate.

Results of repeated measures ANCOVAs with condition (episodic vs. control) as the within-subjects factors and each of the demand indices as the outcomes, controlling for imagery differences, AUDIT scores and gender (on account of potential demand differences between males and females; J. C. Gray & MacKillop, 2014) revealed a significant effect of condition on intensity of demand, which was significantly lower in the episodic condition relative to the control condition (see Table 3.1). An interaction between condition and order revealed an order effect, such that the difference between intensity of demand was found only for participants who did the episodic condition first $F$ (1, 37) = 5.87, $p = 0.02$, $\eta_p^2 = .14$. No significant differences between the conditions were found for $O_{max}$, $P_{max}$, breakpoint or elasticity. In none of the models was there a significant interaction between condition and any covariate ($p$s > 0.05), and as such the assumption of homogeneity of regression was not violated.

**Table 3.1.** Comparisons between alcohol demand indices in the episodic and control imagery conditions. *Indicates significant at p < 0.05. N = 42. Non-transformed mean values reported for interpretability. Analyses controlled for sex, AUDIT scores and between-condition imagery differences

| | **Control** | | **Episodic** | | | | |
|---|---|---|---|---|---|---|---|
| | *M* | *SEM* | *M* | *SEM* | *F (1, 38)* | *p* | $\eta_p^2$ |
| $O_{max}$ | 36.64 | 6.46 | 28.51 | 3.19 | 2.53 | 0.12 | 0.06 |
| $P_{max}$ | 29.27 | 6.69 | 17.24 | 2.79 | 2.37 | 0.13 | 0.06 |
| Intensity | 6.76 | 0.8 | 5.29 | 0.73 | 4.11 | 0.0497* | 0.1 |
| Breakpoint | 32.04 | 4.26 | 34.16 | 5.08 | 1.16 | 0.29 | 0.03 |
| Elasticity | 0.01 | 0.002 | 0.01 | 0.002 | 0.47 | 0.5 | 0.01 |

### 3.4. Discussion

This experiment investigated the impact of episodic foresight on intertemporal choices and alcohol demand. In line with our initial hypotheses, results demonstrated that imagining personally relevant future events during the monetary ICT attenuated the rate at which delayed rewards were discounted. Furthermore, cued episodic future thinking during the APT led to a small reduction in demand 'intensity' (demand at zero cost). However, contrary to our hypotheses, all alcohol demand indices aside from intensity were unaffected when participants engaged in episodic foresight during the APT. Collectively, these findings demonstrate a causal influence of cued future thinking on choice impulsivity generally, but suggest that this influence may only extend to certain aspects of alcohol-related decision-making.

Craving for alcohol plays an important role in impulsive alcohol use behaviours, and existing research on the cognitive and motivational aspects of this craving process place mental imagery central to potential intervention outcomes (Connor et al., 2014; Kavanagh, Andrade, & May, 2005; Kemps & Tiggemann, 2007; May et al., 2014). In line with recent recommendations for clinical innovation (Kavanagh et al., 2014), the current results suggest that encouraging prospective (future-oriented) imagery may bolster the effectiveness of mental imagery in reducing impulsive behaviours. However, the small effect size and marginal significance value of the 'intensity' index mean these results should be interpreted with caution. Additionally, none of the other four APT demand indices were attenuated in the episodic foresight condition relative to the control imagery condition.

The specific mechanisms underlying the effect of episodic foresight on intertemporal decision-making remain unclear (Bulley, Henry, et al., 2016). It is worth noting that the episodic cues used in this experiment were general future events and ostensibly not related to the reward-domain at hand. One possibility is that engaging in episodic foresight serves to shift time horizons towards the future, thereby increasing the salience of future goals and outcomes and informing about the utility of future rewards (Boyer, 2008; H. Lin & Epstein, 2014). More research remains to be done in order to determine how the specific reward content of imagined future events might influence intertemporal choice processes (see Dassen et al., 2016), as well to discern the relative contributions of episodic and semantic processing in this personal event cuing effect (see also Kwan, Craver, et al., 2015; Palombo et al., 2015; Thom & Clayton, 2015).

There are some limitations to the current study. Firstly, rewards in both the ICT and APT were hypothetical. While choice patterns on both of these tasks have been found to correspond with actual monetary rewards and alcohol, respectively (Amlung et al., 2012; Lagorio & Madden, 2005), it would nevertheless be informative to determine whether the effect of episodic foresight operates comparably when real access to alcohol is provided. Secondly, the current study was conducted with a relatively small college student sample that endorsed relatively low levels of problematic drinking. Future research will therefore be needed to determine the generalizability of these results to populations with higher rates of problematic alcohol use. Indeed, a recent study by Snider et al., (2016), found that cued episodic future thinking reduced both delay discounting in a monetary choice task and intensity of demand in an alcohol purchase task in a sample of alcohol dependent individuals.

In conclusion, the present study demonstrates a causal influence of cued episodic foresight in reducing delay discounting, and suggests a potential role for episodic foresight in attenuating alcohol demand intensity. By coming to better understand the circumstances in which engaging in episodic foresight modifies intertemporal and impulsive choice patterns, researchers and practitioners may be able to develop novel, prospective imagery-based intervention strategies for behavioural disorders characterized by the prioritization of immediate over long-term rewards.

## Chapter Four. Thinking about threats: Memory and prospection in human threat management

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**Preface and details of contribution to authorship**:

This chapter presents a taxonomy of threat-related cognition in memory and foresight that connects disparate approaches to anxiety and mental time travel. The chapter outlines how the various components of this taxonomy empower people to manage anticipated threats, but also how these same processes lie at the heart of contemporary anxiety disorders. I conceived the idea, did the research and wrote the first draft. Julie D. Henry and Thomas Suddendorf provided critical revisions.

**Abstract**

Humans have evolved mechanisms for the detection and management of possible threats in order to abate their negative consequences for fitness. Internally generated ('detached') cognition may have evolved in part because of its contributions to this broad function, but important questions remain about its role in threat management. In this article, we therefore present a taxonomy of threat-related internally generated cognition comprising episodic and semantic formats of memory and prospection. We address the proximate mechanisms of each of the capacities in this taxonomy, and discuss their respective contributions to adaptive threat management in humans. For instance, mental time travel empowers people to contemplate and learn from threats experienced long ago, as well as to plan for dangers that might arise in the distant future. However, despite their functional benefits, these thought processes are also central to contemporary anxiety disorders and may be a potent source of distress.

### 4.1. Introduction

> Fear keeps pace with hope. Nor does their so moving together surprise me; both belong to a mind in suspense, to a mind in a state of anxiety through looking into the future. Both are mainly due to projecting our thoughts far ahead of us instead of adapting ourselves to the present. Thus it is that foresight, the greatest blessing humanity has been given, is transformed into a curse. Wild animals run from the dangers they actually see, and once they have escaped them worry no more. We however are tormented alike by what is past and what is to come. A number of our blessings do us harm, for memory brings back the agony of fear while foresight brings it on prematurely.
>
> – SENECA, 60AD

Some capacity for defence in the face of immediate danger is perhaps a universal attribute of all animal species. It has long been recognised that humans, like many other animals, have evolved complex suites of physiological and cognitive processes to detect and manage potential threats to fitness (Cannon, 1916; Darwin, 1872). The distinction between immediately perceptible or *manifest* threats, on the one hand, and *potential* threats on the other has since been used to discern defensive responses to threat in terms of temporal proximity (D. C. Blanchard, Griebel, Pobbe, & Blanchard, 2011; Boyer & Lienard, 2006; Eilam, Izhar, & Mort, 2011; Woody & Szechtman, 2011). A loosely conceptualised gradient has therefore been drawn between defensive reactions to immediate threats ('fear') and defensive reactions to potential threats ('anxiety'). In both cases, however, an animal may use cues in the environment to assess the presence of threat, and to thereby launch the appropriate response(s). However, detection and preparation for potential threats can extend, at least in humans, beyond a response tethered to perceptible cues in the environment. A capacity for internally generated thinking enables humans to represent potential future threats (prospectively) or reflect on those that they have already experienced (retrospectively), without having to rely on information available in their immediate surroundings (J. Pearson, Naselaris, Holmes, & Kosslyn, 2015; Schooler et al., 2011; Suddendorf & Corballis, 2007).

In this paper, we present a taxonomy of threat-related internally generated cognition that comprises episodic and semantic formats of memory and prospection, based on an earlier taxonomy presented by Suddendorf and Corballis (2007). For each of the capacities in this taxonomy, we address both proximate mechanisms (in terms of content and phenomenology, cognitive characteristics, development and underlying neurobiology), as well as ultimate questions (in terms of evolutionary heritage and function). As was recognised by early thinkers in ethology (Mayr, 1961; Tinbergen, 1963), there is utility in embedding mechanistic explanations in their proper evolutionary context (Scott-Phillips, Dickins, & West, 2011). Thus, while Seneca in the opening quote regards threat-related memory and prospection as a curse, we propose that despite their costs for wellbeing, these capacities have characteristics that suggest they have been shaped by natural selection as tools in the struggle for survival and reproduction.

**4.2. What are threats?**

We here broadly define a threat in evolutionary terms, in line with previous accounts (J. A. Gray & McNaughton, 2003; Marks & Nesse, 1994), as any aspect of the environment that could be detrimental to the fitness of the organism. Humans have evolved systems to detect and manage at least certain classes of these threats that have been encountered over many generations in ancestral environments (A. T. Beck et al., 1985; D. C. Blanchard et al., 2011; Neuberg, Kenrick, & Schaller, 2011; Sherlock, Zietsch, Tybur, & Jern, 2016; D. J. Stein & Nesse, 2011; Tooby & Cosmides, 1990). Our forebears were no doubt regularly confronted with many types of potential threats, ranging from the quasi-universal risk of attacks by predators (Barrett, 2005; Hart & Sussman, 2005; Mobbs, Hagan, Dalgleish, Silston, & Prévost, 2015) to more subtle risks such as a loss of social status with potentially severe implications for access to cooperative partners, mates, or resources (Bulley, Miloyan, Brilot, Gullo, & Suddendorf, 2016; P. Gilbert, 2001; Trower, Gilbert, & Sherling, 1990).

It has been suggested that different, albeit somewhat overlapping, processes have evolved in humans for the detection and management of threats in different domains and under different circumstances (C. D. Blanchard, Hynd, Minke, Minemoto, & Blanchard, 2001; Harrison, Ahn, & Adolphs, 2015; Marks & Nesse, 1994; D. J. Stein & Bouwer, 1997). Detecting a cue of social threat (i.e. to one's status), for example, entails a different set of processes than detecting a cue that a predator is lurking nearby (Sterelny, 2003). For instance, a social threat to status may uniquely require the visual decoding of signs of disapproval on another person's face and interpretation of their intentions. However, there are also shared aspects of threat-detection and response to seemingly disparate threats, such as a state of enhanced vigilance that is useful for many kind of dangers (Brilot, Bateson, Nettle, Whittingham, & Read, 2012; Eilam et al., 2011; Mobbs et al., 2015). Different anxiety responses may therefore represent partially segregated systems for the detection and subsequent management of different classes of threat encountered in past environments, particularly in cases where a generalized response would not sufficiently mitigate the risk (Brilot et al., 2012; Cosmides & Tooby, 1994; McNaughton, 1989; Nesse, 1990; Tooby & Cosmides, 1990). These different detection and response processes manifest at extreme levels as the various subtypes of anxiety observed in contemporary humans. Social anxiety disorder, for instance, can be conceptualised as the pathological expression of the adaptive social anxiety trait that evolved because it facilitates the navigation of complex social hierarchies (P. Gilbert, 2001; D. J. Stein, 2015; Trower et al., 1990).

A common distinction in the threat-management literature is between immediate or *manifest* threats on the one hand, and *potential* future threats on the other (Boyer & Lienard, 2006; Eilam et al., 2011). It is now widely agreed that animals respond to immediately perceptible manifest threats (i.e. the emergence of a predator from behind a bush) with 'fear' and/or a 'defensive' response (see Adolphs, 2013; LeDoux, 1998). In contrast, when detecting and responding to cues of *potential* (future) threats (i.e. the sound of leaves rustling), an anxiety response is more typical. In both cases, however, cues in the perceptual environment form the basis of these responses.

Humans are additionally capable of representing threats even in the absence of any relevant sensory cues through the mental simulation of past and future scenarios (Boyer & Bergstrom, 2011; Miloyan, Bulley, et al., 2016; Mobbs et al., 2015; Perkins, Arnone, Smallwood, & Mobbs, 2015; Suddendorf & Corballis, 2007). Humans are also capable of the abstract, general representation of threat by drawing on semantic knowledge about how the environment used to be, or how it might be in the future (Wu et al., 2015). Together, these capacities afford enormous flexibility in how an individual can respond behaviourally to a variety of potential dangers without being limited to currently incoming perceptual cues. We now turn to a discussion of future-oriented threat-detection and response in humans, by considering the contribution of both episodic and semantic processes.

### 4.3. Semantic and episodic processes in internally generated thinking

Traditionally, declarative memory refers to the capacity to process information that can be explicitly recalled, and thus consists of both facts or knowledge about the world – semantic memory - as well as autobiographical details about one's experiences - episodic memory (Martin-Ordas, Atance, & Caza, 2014; Raby & Clayton, 2009; Squire, 1992; Tulving, 1972, 1985). Semantic memory is therefore generally conceptualised as being 'knowledge-based' and episodic memory as 'event-based'. Tulving (1985b) suggested that while episodic memory was hallmarked by a kind of 'autonoetic' ('self-knowing') consciousness that involved the first-person subjective experience of previously lived events, semantic memory instead was a form of 'noetic' (knowing) consciousness that did not require such mental simulation (see also Szpunar & Tulving, 2011; Wheeler, Stuss, & Tulving, 1997). These memory processes are now considered integral to thinking about or imagining the future (*prospection*), and while they rely on partly dissociable neural systems, their interdependence is essential for episodic 'mental time travel' in both temporal directions (Irish et al., 2012; Irish & Piguet, 2013; Klooster & Duff, 2015; Martin-Ordas, Atance, & Louw, 2012; Suddendorf & Corballis, 1997, 2007; Szpunar, 2010; Szpunar et al., 2014). However, the contributions of these sub-systems to threat management processes have not, to our knowledge, been discussed.

The distinction between episodic and semantic processes coincides with research on 'representational formats' or 'modes' of thinking that emphasize verbal versus imagery coding schemes (Paivio, 1986; see also Stawarczyk, Cassol, et al., 2013). In memory and prospection, semantic knowledge is usually conceptualised as abstracted and primarily verbal-linguistic, whilst episodic knowledge is more commonly conceptualised as an imagery-based thought process involving the projection of the self into mentally constructed scenarios of another time or place (Buckner & Carroll, 2007; Klein, Loftus, & Kihlstrom, 2002; Kosslyn, 1980; Suddendorf & Corballis, 2007). Note, however, that this does not rule out imagery-based representations of semantic facts, or verbal-linguistic representation of episodic events. Some authors have argued that episodic processes should be regarded as a general mental scenario building capacity that encompasses the internal generation of mental imagery relating not only to past and future events, but also fictitious scenarios, theory of mind, dreaming, and more generally creative thought (Addis et al., 2007; Domhoff & Fox, 2015; Dong, Collier-Baker, & Suddendorf, 2015; Hassabis & Maguire, 2009; Mullally & Maguire, 2013; Suddendorf, 2013).

From a neural perspective, a number of authors have proposed that these varied imagery-based activities are the product of the *default mode network* of brain regions that includes the medial temporal lobe, midline prefrontal cortex, and cingulate cortex (Buckner, Andrews-Hanna, & Schacter, 2008; Konishi, Mclaren, Engen, & Smallwood, 2015; Raichle et al., 2001; Smallwood, Tipper, et al., 2013; Spreng & Grady, 2010). Recent studies also demonstrate a large overlap between the default mode network and the ‘semantic knowledge network’ (Binder, Desai, Graves, & Conant, 2009), and the results of lesion studies suggest that semantic knowledge plays a critical – if not pivotal – role in episodic cognition (Binder & Desai, 2011; Irish et al., 2012; Irish & Piguet, 2013).

In sum, semantic and episodic processes collectively comprise dissociable but interacting forms of ‘internally generated thinking’ (Smallwood & Schooler, 2015; Suddendorf & Corballis, 2007; Szpunar et al., 2014). In both cases, these processes entail ‘detached’ representations that are not entirely contingent upon cues drawn from the immediate perceptual environment, despite the influence these cues might have on resulting content and phenomenology (Gardenfors, 1995). Together, episodic and semantic processes enable the spatiotemporally detached representation of threats in different ways – both in retrospective memory and in prospective cognition (see MacLeod et al., 1997). We will explore how these processes provide diverse mechanistic inroads to the same adaptive challenge of detecting and managing threats to fitness en route to opportunity. Figure 4.1 presents a taxonomy of these four interrelated aspects of threat-related internally generated thinking, each of which we now survey in turn.

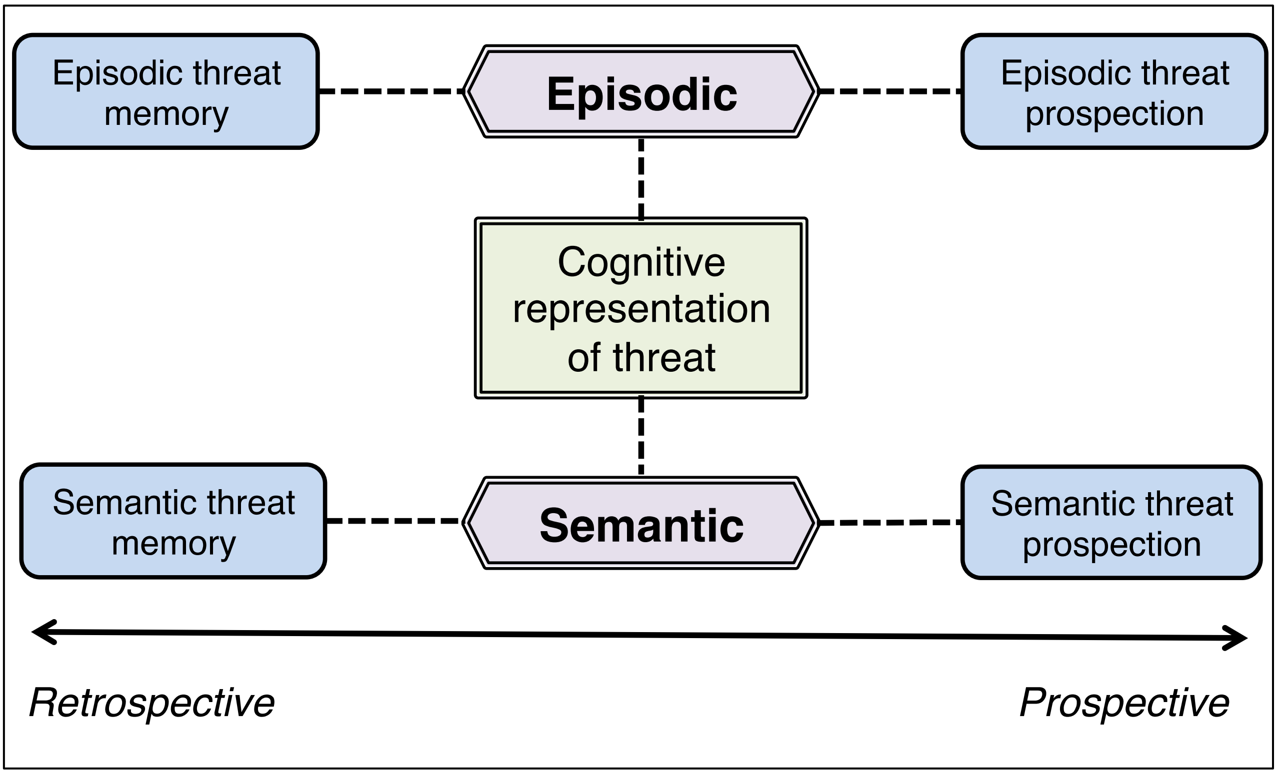


*Figure 4.1.* A taxonomy of threat-related internally generated cognition. Threats can be represented in both episodic and semantic formats, either retrospectively or prospectively. Note that the distinction between episodic and semantic processes is illustrative only, and is not meant to imply unidirectional or independent relationships.

**4.4. Prospection and preparation**

The mental representation of future threats has long been a central focus of cognitive models of anxiety (A. T. Beck et al., 1985; MacLeod & Byrne, 1996). Findings of recent studies suggest that in fact most internally generated thinking that naturally arises during daily life is future-oriented, and often emotionally charged, implying that such thinking routinely engenders a form of adaptive goal identification and planning that necessarily involves the identification of potential threats as well as opportunities (Baird et al., 2011; Barsics et al., 2015; D'Argembeau et al., 2011; Finnbogadóttir & Berntsen, 2011, 2013; Poerio, Totterdell, & Miles, 2013; Song & Wang, 2012). In lay usage, the word 'worry' often denotes the mental representation of negative future possibilities, and a large body of research now underscores the centrality of prospective representations to threat-management and anxiety disorders (Borkovec & Inz, 1990; Borkovec & Ray, 1998; Finnbogadóttir & Berntsen, 2011; Hirsch & Mathews, 2012; Szabó & Lovibond, 2002).

‘Worry’ has been defined in the clinical literature as the predominantly abstracted, verbal representation of future threats (Borkovec & Ray, 1998). It has been conceptualized as relying primarily on semantic, rather than episodic, processes (Behar, DiMarco, Hekler, Mohlman, & Staples, 2009; Borkovec & Lyonfields, 1993; Borkovec & Ray, 1998; Freeston, Dugas, & Ladouceur, 1996; Stöber, 1998; Stöber, Tepperwien, & Staak, 2000). Although threats can, and often are, represented with both semantic and episodic processes, each may contribute to threat detection and management in somewhat different ways (see Table 4.1). We therefore distinguish the notion of *semantic threat prospection,* which is characterised mostly by verbal and abstracted representations of threat (commonly called ‘worry’ in clinical psychology) from *episodic threat prospection*, which is characterised mostly by vivid and narrative mental simulations of possible threat events. Although much research has been conducted on semantic threat prospection, probably because this is the type of thought process most often associated with clinical anxiety, (especially GAD; Hirsch, Hayes, Mathews, Perman, & Borkovec, 2012), only more recently has episodic threat prospection become the focus of intense research interest (Finnbogadóttir & Berntsen, 2011; Jing, Madore, & Schacter, 2016; Miloyan, Pachana, et al., 2014; Wu et al., 2015). We now discuss episodic and semantic threat prospection in turn.

### 4.4.1. Episodic threat prospection

Episodic threat prospection involves the simulation of future threat-related mental scenarios. More specifically, an individual can create narratives involving possible future threat events (detection) by projecting the self into the future, as well as generate strategies, plans and intentions to deal with those threats (management). For example, a person who wishes to embark upon a journey in a freezing tundra climate may envisage the biting pain of the cold weather, and imagine multiple potential problematic situations that could arise in order to assemble the most appropriate equipment to bring along. This is an ability that relies on a suite of interacting component processes including some capacity for meta-representation and the nesting of imagined scenarios (Redshaw, 2014; Suddendorf, 2013), and occurs frequently both voluntarily and involuntarily (i.e. without wilful effort) in everyday life (Berntsen & Jacobsen, 2008; Busby Grant & Walsh, 2016; Finnbogadóttir & Berntsen, 2011).

In the brain, episodic simulations of future scenarios are tied to neural activity across a distributed network of default mode regions and conceptual knowledge hubs, centrally subserved by hippocampal activity (Addis et al., 2007; Binder & Desai, 2011).

Associated neural activity in prefrontal valuation and emotion processing areas is involved in encoding the biological value of imagined stimuli (Andrews-Hanna, 2012; Benoit et al., 2014; Hakimi & Hare, 2015). Mentally simulated objects or events can thereby evoke an affective response 'as if' the stimulus were being directly perceived (Hesslow, 2002; J. Pearson et al., 2015), and can subsequently influence decision-making and behaviour over long timescales (Ainslie, 2007; Boyer, 2008; Bulley, Henry, et al., 2016; Damasio, 1989, 1996; D. T. Gilbert & Wilson, 2007; K. Meyer & Damasio, 2009; Miloyan, Bulley, et al., 2016). In practice, this also means that valuation signals from diverse brain regions, including the amygdala (see Seymour & Dolan, 2008), may interact with decision-making networks to modify current action via emotionally salient imagined future threat events. It is in this way that people can predict how they will feel in response to future events, and act in light of these predictions (D. T. Gilbert & Wilson, 2007; Rachman, 1994; Suddendorf & Busby, 2005; T. D. Wilson & Gilbert, 2005a, 2005b).

Indeed, there is now a growing literature indicating that mental imagery-based thought processes elicit greater emotional reactions than verbal representations (Holmes & Mathews, 2005; Ji, Heyes, MacLeod, & Holmes, 2016; J. Pearson et al., 2015). A simple introspective exercise illustrates this point: vividly imagining crashing your car on the way home from work is more unpleasant than merely stating the fact that you might be in such an accident. For this reason, episodic (to a greater extent than semantic) threat prospection enables the individual to flexibly anticipate the emotional costs (i.e. negative biological value) as well as the likelihood of various possible dangers, thereby flexibly modulating decision-making and behaviour in light of anticipated future possibilities (Bulley, Henry, et al., 2016). It is worth noting that even a highly unlikely danger can be expected to exert large selective pressure on mechanisms for representing possible threats if it is associated with an extremely high cost such as death (Woody & Szechtman, 2011).

It has been argued that because episodic simulations of costly future threat events are often emotionally charged (D'Argembeau et al., 2011), they play an important motivational role in avoiding or abating potential dangers (Boyer & Bergstrom, 2011; Miloyan, Bulley, et al., 2016). Once an individual has derived information about the negative value of an anticipated event, this then determines their motivation to act upon that simulation (Miloyan & Suddendorf, 2015). Episodic threat prospection therefore interfaces directly with older, emotional regulatory mechanisms for the avoidance of threat - e.g. those found in a 'core self' common to mammalian species (Northoff & Panksepp, 2008) - and can spur the engagement of avoidance or preparatory behaviours involved in preventing or overcoming future dangers. Nonetheless, these emotionally charged simulations can also feed back to negatively impact mood and may therefore be costly to wellbeing in some circumstances despite their clear adaptive functions (Perkins et al., 2015; Poerio et al., 2013; Ruby, Smallwood, Engen, & Singer, 2013; Stawarczyk, Majerus, & D'Argembeau, 2013). Indeed, recent evidence suggests that the capacity to suppress anticipatory simulations of fearful events may be important in regulating anxiety about the future (Benoit, Davies, & Anderson, 2016).

Once capable of simulating future situations and threats, and remembering these thoughts sufficiently to compare them with what subsequently occurred, one can begin to abstract more general rules about potential threats that may lurk in the future. This allows humans to worry about what might be even without vividly simulating concrete future scenarios. We now turn to a discussion of this 'semantic' threat prospection process.

#### 4.4.2. Semantic threat prospection

As mentioned, most previous studies of future threat representation have focused on semantic threat prospection, which comprises generalized and abstract chains of thoughts about possible future negative outcomes, and is primarily verbal and generally sparse in mental imagery (Borkovec & Inz, 1990; Borkovec, Robinson, Pruzinsky, & DePree, 1983; Stöber & Borkovec, 2002). The ability to represent a possible future threat on the basis of generalized semantic knowledge about the nature of the world (e.g. "cold weather requires warm clothes", "tigers may attack" or "climate change may cause floods") does not require the generation of mental simulations about these possibilities (Klein, Loftus, et al., 2002). This is future thinking in semantic terms because it is the projection forward of abstract factual knowledge about the world that represents how things might be in the future (Atance & O'Neill, 2001).

Indeed, Gray and McNaughton (2003) argue that anxiety has become much more substantial (and pathological) in humans because of the emergence of a verbal representational capacity (J. A. Gray & McNaughton, 2003, p. 138). For example, one of the characteristic features of some anxiety disorders is so-called 'meta-worry'. This comprises verbal-linguistic/ conceptual worries *about worrying itself*, such as "if I keep worrying I am going to give myself a heart attack" or "my worrying is getting out of control" (Wells, 1995, 2005). This meta-worry is associated with a large degree of attendant suffering, and is unlikely to represent a targeted adaptive response to environmental threats (Kennair, 2007). Instead, this thought-process may be made possible in humans by the joint operation of open-ended recursive language and metacognition, alongside a degree of self-awareness (Corballis & Suddendorf, 2007; Hauser, Chomsky, & Fitch, 2002; Thielsch, Andor, & Ehring, 2015). Meta-worry may therefore be the by-product of these complex human abilities, interacting together along with physiological systems responsible for regulating anxiety (see Kennair, 2003, 2007).

With this said, a capacity to represent past and future threats semantically may provide a number of adaptive benefits when not expressed as 'worrying about worrying'. For instance, semantic threat prospection enables the generation of a storehouse of information about what may be threatening in the future environment, the rapid retrieval of this knowledge when appropriate, and the co-operative sharing of this information with conspecifics. Generally, semantic knowledge about the world is organized into conceptual categories on the basis of shared essential properties between informational elements. This includes criteria such as stimulus features, temporal relationships, and affective information (Barsalou, 1999; V. Evans, 2006). When worrying about spatiotemporally detached threats, the individual can thereby rapidly access relevant pieces of information (about the threat, its cause, or how to manage it, e.g. what tools would be appropriate) on the basis of a present environmental circumstance or an internally generated thought during planning (Doré, Ort, Braverman, & Ochsner, 2015; Klein, Robertson, & Delton, 2011).

However, it is important to note that semantic worry frequency has not been found to improve problem-solving ability *per se,* and may in some cases instead interfere (Davey, 1994; Dugas, Letarte, Rhéaume, Freeston, & Ladouceur, 1995; Ladouceur, Blais, Freeston, & Dugas, 1998), suggesting that its function may be more to do with alerting the individual to the presence of potential threats and related information, rather than solving them. Solving these threats may be a task better reserved for the planning made possible by episodic threat prospection. Indeed, there is now a body of evidence suggesting that verbal worrying can facilitate *attention* to threat (Oathes, Squillante, Ray, & Nitschke, 2010; M. O. Williams, Mathews, & Hirsch, 2014), but that it is hardly ever 'solution-focussed' which is what would be expected of a cognitive process whose function is to generate response strategies for threat encounters (see Kennair, 2014). These findings nonetheless suggest that functional threat *detection* can be facilitated without a full episodic simulation of a future threat possibility.

Over time, people may come to rely more on semantic representations rather than episodic ones, as the latter can become superfluous once an environmental regularity has been established through learning. One reason for this shift is that the use of semantic representations to solve problems may be less costly (e.g. temporally or in terms of computational efficiency) than episodic ones (Klein, Cosmides, Tooby, & Chance, 2002). Episodic processes, however, remain important in that they allow representation of the particularities, rather than regularities, of past and potential future events (Suddendorf & Corballis, 2007). Indeed, episodic threat prospection may, in turn, draw upon semantic knowledge about a threat in the process of creating complex narratives about its possible specific manifestation or how to manage it if and when it happens (Cheng, Werning, & Suddendorf, 2016).

Interestingly, semantic threat prospection may additionally serve a ‘self-protective’ role in coping with unpleasant anxiety evoked by episodic processes. Borkovec (1990) and others have suggested that worry (in the semantic threat prospection sense) is thereby a type of avoidance coping for dealing with the unpleasant generation of mental imagery (Borkovec, Alcaine, & Behar, 2004; Borkovec et al., 1983; Borkovec & Lyonfields, 1993; McGowan et al., 2017; Stöber, 1998; Stöber & Borkovec, 2002; Stöber et al., 2000). More specifically, because mental imagery is often more emotionally salient than verbal representations, people may strategically engage in semantic threat prospection in order to suppress the negative emotions that would otherwise be triggered by mental imagery. A full discussion of this proposition is beyond the scope of this article (but see Behar et al., 2012, 2009; Borkovec et al., 2004; Eysenck & Van Berkum, 1992; Finnbogad & Berntsen, 2011; Ottaviani et al., 2014).

### 4.5. Retrospective memory and threats

> If I step aside on seeing a rattlesnake, from considering how dangerous an animal he is, the mental materials which constitute my prudential reflection are images more or less vivid of the movement of his head, of a sudden pain in my leg, of a state of terror, a swelling of the limb, a chill, delirium, unconsciousness, etc., etc., and the ruin of my hopes. But all these images are constructed out of my past experiences. They are reproductions of what I have felt or witnessed. They are, in short, remote sensations.
>
> – WILLIAM JAMES, 1890

Prospective cognition is, by definition, geared towards future possibilities. However, as James (1890) argued, such thoughts are “reproductions” of a sort – they are built out of elements from memory (Suddendorf & Corballis, 2007; Szpunar & McDermott, 2008). Indeed, prospective cognition is generated from the ingredients accrued though lived experience – regardless of whether this knowledge is semantic or episodic, suggesting that memory is in essence forward-facing inasmuch as it empowers an organism to prepare for the future (Baumeister et al., 2016; Ingvar, 1985; Klein, 2013b; Klein, Robertson, & Delton, 2010; Seligman et al., 2013; Suddendorf & Corballis, 1997; Suddendorf & Henry, 2013).

The ability to generate novel expectations about future events relies in part on the recursive nesting of the information accrued through past experience (Hassabis & Maguire, 2009; Spreng et al., 2009; Suddendorf & Corballis, 1997, 2007), and similar processes underlie the reconstruction of past episodes (Busby & Suddendorf, 2005; Schacter & Addis, 2007). The important role of mnemonic representations has previously been alluded to in cognitive accounts of future threat representation by authors since James (1890). For instance, Eysenck (1992) wrote: "Worry is triggered by a threat… the threat may be in the form of an environmental stimulus or it may be in the form of activated information in long-term memory" (Eysenck, 1992, p. 116). Thus, semantic and episodic memories provide the 'raw material' from which prospective thoughts are constructed. However, mentally revisiting previously experienced threat events in memory may also serve a range of other preparatory functions (Boyer, 2009), for instance by enabling a decision-maker to consider what went wrong in the past, and why – with implications for how to behave differently next time in the event of a reoccurrence. Indeed, recent experimental work by Nairne and colleagues suggest that memory systems are adapted to prioritise information of fitness-relevance – including a range of threats (Nairne, 2010; Nairne & Pandeirada, 2008; Nairne, Pandeirada, Gregory, & Van Arsdall, 2009; Nairne, Pandeirada, & Thompson, 2008; VanArsdall, Nairne, Pandeirada, & Cogdill, 2015). We now turn to a discussion of the ways in which a capacity for episodic and semantic memory broadly might facilitate future threat management moving forwards.

#### 4.5.1. Episodic threat memory

The episodic recollection of previously encountered threats can enable the individual to re-play the past, learn from the consequences of their actions, and to entertain how alternative histories may have unfolded had they acted differently. Anxious individuals consistently exhibit a bias for threat-related information during the retrieval of episodic memories (for review see Zlomuzica et al., 2014). For example, individuals with social anxiety disorder tend to recall threatening social situations from the perspective of another rather than from their own perspective (Wells, Clark, & Ahmad, 1998). Socially anxious individuals also show enhanced recall, specificity and emotionality of social threat-related autobiographical memories (Krans, de Bree, & Bryant, 2014; Morgan, 2010; Wenzel & Cochran, 2006). Collectively, these results suggest a tendency amongst socially anxious people to reflect on social situations in a manner conducive to learning (i.e. by vividly imagining their own performance), motivated by the potential improvements to performance that this might enable. Indeed, a number of studies have found that higher specificity (more episodic details) in autobiographical memory retrieval generally is associated with better problem-solving capacities (A. D. Brown, Dorfman, Marmar, & Bryant, 2012; Vandermorris, Sheldon, Winocur, & Moscovitch, 2013). Such findings suggest that vivid episodic recollection may confer their beneficial effects by enhancing interpretation and learning from previous encounters.

Episodic memories are not facsimile images of past events, and their reconstructive nature leaves them prone to biases and errors (Damasio, 2010; Schacter, 2001; Schacter & Addis, 2007; T. D. Wilson & Gilbert, 2005b). Indeed, as mentioned, the adaptive significance of memory may be largely attributed to its role in preparing individuals for the future, rather than accuracy in past recall per se (Suddendorf & Henry, 2013). However, the reconstructive nature of memory not only enables informational elements to be combined to construct novel future events, but also to construct novel *counterfactual simulations* of alternative histories using if-then conditionals (Barbey, Krueger, Grafman, & Bar, 2011; Roese, 1997; Schacter, Benoit, De Brigard, & Szpunar, 2015). For example, in remembering an anxiety-provoking social blunder, one could imagine having used an alternative turn of phrase that might have evoked warm laughter rather than uncomfortable silence. Recent neuroimaging evidence suggests that such counterfactual simulations engage the common core network involved in other episodic processes including episodic memory and foresight (Schacter et al., 2015).

A number of the features of counterfactual simulations suggest they are well tuned to serve an adaptive function (Byrne, 2007; Epstude & Roese, 2008). For example, counterfactual simulations most commonly occur after negative outcomes (Roese, Sanna, & Galinsky, 2005) and are often centrally focussed on aspects of controllability – things that the individual perceives ‘could have been done differently’ (Byrne, 2002; Girotto, Legrenzi, & Rizzo, 1991). Counterfactual simulations relating to negative events are tied closely to the emotion of regret. And, despite being unpleasant, regret may be adaptive insofar as it enables one to avoid repeating past mistakes with a view towards the future (Hoerl & McCormack, 2016; Saffrey, Summerville, & Roese, 2008). For instance, in a recent experiment children who experienced regret about a simple decision were more likely to change their choice when given the same decision again (O'Connor, McCormack, & Feeney, 2014).

Thus, counterfactual simulations may play a key role in learning from past encounters alongside episodic memory because they allow people to determine alternative courses of action that might have better handled a perceived stressor (Byrne, 2002). Support for this view comes from the fact that counterfactual thinking appears to improve subsequent performance in various tasks (Morris & Moore, 2000; Roese, 1994; Van Hoeck et al., 2012). Increased counterfactual thinking has also been associated with some specific anxiety disorders (e.g. Kocovski, Endler, Rector, & Flett, 2005; Prokopcáková & Ruiselová, 2008) suggesting that retrospective counterfactuals may be an important aspect of threat-related internally generated thinking. Taken together, the above evidence supports the idea that threat-related counterfactuals that use episodic memory processes may facilitate future threat preparation and management, and therefore have an important evolutionary function in this domain.

### 4.5.2. Semantic threat memory

Semantic memory often represents factual knowledge about the general environment, but can also refer to one's own self or life (Renoult, Davidson, Palombo, Moscovitch, & Levine, 2012). For instance, one might *know* that the scar on one's arm was caused by a bite from a dog during childhood, but this does not necessitate a full mental simulation of the event every time one recalls this fact. Although episodic memory impairments may lead to impairments in semantic recall (Klooster & Duff, 2015), semantic memory is unique in that it provides a lingering knowledge of past threats in abstracted terms.

This abstracted semantic knowledge can be learned via personal experience (as per the dog bite example above), but may also be socially transmitted. This means people can learn vicariously from others about threats in their environment, and these facts can incorporate valuation information (Boyer & Parren, 2015). For instance, one can learn which particular stimuli and categories of stimuli are threatening, like the food items that are poisonous or the weather changes that signal a storm. A sign by a river that reads: "beware of crocodiles", for instance, can thus effectively impart factual knowledge about an environmental threat. Thus, while semantic threat memories are useful individually, humans can also collectively pool together factual information about dangers in their environment, as well as the most appropriate responses to these threats. Of course, this possibility does not arise unless humans are motivated to seek out information of this nature and to share it with one-another (Suddendorf, 2013). Indeed, cooperative sharing of information of all kinds (including future plans) would have been a boon to early hominins. With this said, there is little of more relevance to fitness than information about which aspects of the environment are harmful. Among other benefits afforded by cooperation and information-sharing, access to a collective repository of threat knowledge may therefore have provided a critical adaptive advantage to willingly cooperative early humans attempting to navigate dangerous and unpredictable environments.

In the clinical domain, there is a tendency towards the overgeneralization or semanticisation of memories in some anxiety disorders, particularly those precipitated by traumatic events (A. D. Brown, Addis, et al., 2013). A number of theorists have suggested that these changes reflect a motivated avoidance of traumatic memories that might instigate emotional distress during retrieval, such that individuals will avoid recalling specific threat-related episodic memories and instead opt to report general categories of events (for reviews see Moore & Zoellner, 2007; J. M. G. Williams et al., 2007; Zlomuzica et al., 2014). The phenomenon of overgeneral memory in anxiety-related psychopathology serves to further underscore the heterogeneity of memory processes in the anxiety disorders. For instance, overgeneral memory is not typically observed in other anxiety disorders, including social anxiety disorder, generalised anxiety disorder, or specific phobia, which are in some cases in fact associated with an intensification of some elements of episodic recall (for review see Zlomuzica et al., 2014).

The generality of memories (and foresight) in trauma-related anxiety disorders such as PTSD may represent an ancient and efficient solution for predicting future threats on the basis of cues that were associated with previous environmental stressors. Evolutionary accounts of PTSD recognise that hyperactivity in the amygdala and other neural structures involved in inferring the presence of threats in the environment are sensitized through learning after experiences of great distress and danger (D. M. Diamond & Zoladz, 2015). While a specific episode of experienced trauma is unlikely to repeat in exactly the same way, broader and more abstract semantic knowledge about threats drawn from these events can be useful for general preparation (Miloyan, Bulley, et al., 2016). Semantic knowledge derived from the traumatic event informs the individual about what is threatening (and should be avoided), thereby providing a mechanism for guiding appropriate action without necessitating a fully-fledged mental simulation of future possibilities. However, evidence that over-general memories occur in other disorders such as depression or anorexia means it may be premature to infer an adaptive role for this process in threat-management specifically, and future research will be required to determine if this shift in memory content reflects a similar underlying process in each instantiation of psychopathology.

Semantic knowledge is not only a crucial ‘ingredient’ in the construction of mental scenarios, but it may also guide and facilitate the construction of episodic cognition (see Klein, Cosmides, et al., 2002). Indeed, it has been suggested that semantic memory underpins episodic processing in both memory and prospection (Binder & Desai, 2011; Irish et al., 2012; Irish & Piguet, 2013), and that semantic knowledge may be integrated into the scenario building process as a crucial aspect of subsequently imagined possibilities (Cheng et al., 2016). Next we turn to the retrieval processes underlying the generation of internally generated thinking in threat-management systems, and the adaptive behavioural responses facilitated by the components of the taxonomy.

**Table 4.1.** Characteristics of four interrelated threat representation processes.

| Internally generated thought process | | Characteristics |
|---|---|---|
| **Prospection** | Episodic threat prospection | ▪ Concrete, specific and flexible<br>▪ Primarily imagery based representation<br>▪ Emotionally salient<br>▪ Enables affective forecasting<br>▪ Motivates the avoidance or management of future threat events<br>▪ Enables flexible (collaborative) planning and goal-setting |
| | Semantic threat prospection | ▪ Abstract and generalised<br>▪ Primarily verbal-linguistic representation<br>▪ Provides a bank of knowledge about potential future threats<br>▪ May facilitate attention to environmental threats |
| **Memory** | Episodic threat memory | ▪ Concrete, specific and flexible<br>▪ Primarily imagery based representation<br>▪ Emotionally salient<br>▪ Facilitates learning through revisiting of past experiences<br>▪ Can involve counterfactual simulations of how a threat could have been managed differently |
| | Semantic threat memory | ▪ Abstract and generalised<br>▪ Primarily verbal-linguistic representation<br>▪ Provides a bank of knowledge about threats in the environment<br>▪ Individually learned or culturally transmitted<br>▪ Enables the rapid retrieval of relevant information during threat-representation |

### 4.6. Retrieval processes and adaptive responses

A large body of research suggests that an anxious affective state precipitates the biased retrieval of threat-related information from memory, inducing a tendency to construct threat-related mental scenarios (e.g. A. Richards & French, 1992). The reconstructive memory model of episodic future thinking in anxiety (Miloyan, Pachana, et al., 2014) suggests that the biased retrieval of information from memory in the process of imagining future events therefore shapes the affective and phenomenological characteristics of those imagined events. Thus, because anxiety has been associated with a suite of threat-related biases in memory retrieval, an anxious mood may cause threat-related episodic foresight (see also Miloyan, Pachana, & Suddendorf, 2016; Miloyan, Pachana, et al., 2014).

The repeated internal generation of threat-related thoughts may also exacerbate an anxious affective state by increasing the subjective plausibility of those events (G. P. Brown, MacLeod, Tata, & Goddard, 2002; Raune et al., 2005; Wu et al., 2015), further biasing the retrieval of threat-related content from semantic and episodic memory. However, the selective retrieval of threat-related content from memory during internally generated thinking may not be solely restricted to instances of current negative affect, and in fact there exists a wide bias in attention and retrieval for threat-related information generally (Baumeister, Bratslavsky, Finkenauer, & Vohs, 2001; Nesse, 2005). Revonsuo (2000) has argued that dreaming serves the adaptive function of preparing the individual to manage upcoming dangers by the recurrent simulation of various possible threats (see also Valli et al., 2005; Valli & Revonsuo, 2006; Zadra, Desjardins, & Marcotte, 2006). Threats, in this hypothesis, are therefore overrepresented (retrieved selectively) in dreams because this facilitates the ultimate goal of detecting and managing future dangers when and if they arise.

The aforementioned retrieval tendencies can come to be associated with significant distress. For a recent review on the mental health and wellbeing implications of semantic and episodic memory and prospection, see MacLeod (2016). Nonetheless, these processes may be considered adaptive inasmuch as they facilitate effective preparation for future threats (Klein et al., 2010; Suddendorf & Corballis, 2007). Representing past or future threats, whether based on semantic or episodic processes, may lead people to engage in a wide variety of adaptive behaviours they might otherwise forego. For instance, humans may acquire relevant resources, create tools or weapons (Hallos, 2005), selectively foster useful alliances (Boyer, Firat, & van Leeuwen, 2015), or practice new skills (Suddendorf, Brinums, & Imuta, 2016) in anticipation of future threats or upon recalling past ones. Episodic processes, for instance, enable people to collaboratively share stories and plans for the management of potential danger, such as the collective production of hypothetical battle strategies if another group were to attack (Suddendorf, 2013). Humans may also differentially allocate behavioural and decision-making effort in the present moment as a function of anticipated threats, for instance in the context of intertemporal decision-making where anticipated future threats might encourage a greater preference for (more certain) immediate rewards (Bulley, Henry, et al., 2016). None of these behavioural strategies would emerge without the capacity to represent future dangers that would otherwise cause harm – or those that have already done so in the past.

Evolutionary theories about cognitive processes often hypothesize adaptation to particular environmental problems faced in ancestral environments (Barkow, Cosmides, & Tooby, 1992). However, this approach faces a challenge in that many useful capacities cannot readily be conceptualised as modules with one circumscribed function. For example, a capacity for operant conditioning is an immensely useful tool for an organism insofar as it enables flexible responses to both potential rewards and punishments. We cannot know which environmental pressures brought it first to existence, and indeed the capacity has a collection of implementations. Likewise, memory and prospection may represent domain-general utilities that provide adaptive benefits for many environmental challenges, not limited to threats (Suddendorf & Corballis, 2007). In turn, these abilities are also immensely useful for dealing with problems they could not possibly have evolved to solve (e.g. planning for an asteroid collision), which must instead be considered helpful current implementations of the evolved capacities (Buss, Haselton, Shackelford, Bleske, & Wakefield, 1998). Thus, the evolutionary argument we make here does not depend on the claim that memory and prospection are uniquely adapted for dealing with threats. It is plausible, however, that certain threats produced particularly potent pressures in forging these capacities.

Consider the following observations. A global shift to a cooler climate occurred some 2.5 million years ago, and much of southern and eastern Africa became more open and sparsely wooded, exposing our ancestors to greater danger from predators. Indeed, unlike our ape relatives and earlier hominins who were adapted to live in the trees, our ancestors at that stage had to adapt to the very different environmental challenges of savannah life. Faced with many species of sabre-toothed cats, hyenas and other predators (see Hart & Sussman, 2005), and in the absence of both sufficient speed and strength to deal with this, selection pressure would have been strong on avoiding these threats and effectively dealing with them when confronted. One strategy would have been cooperative defence, for instance in the form of throwing stones and hence hurting predators before they came within striking distance. This in turn would have selected for preparation, and the carrying of projectiles (Suddendorf, 2013).

The earliest evidence for foresight is that of stone tools that appear to have been transported for repeated use. Reconstruction of knapping routines (using refit data) suggests that at least by the Middle Pleistocene hominins produced stone tools in one site to use them later at another (e.g., Hallos 2005). Savannah-dwelling bipedal hominins may have relied increasingly on throwing stones at predators (Calvin, 1982), and eventually to bring down prey. Carrying rocks for use as missiles at some future point may have been vital, and a capacity to plan for this might have been under strong selection pressure (see Suddendorf & Corballis, 2007). One possibility, then, is that extensive foresight evolved first in the context of cooperative defence from savannah predators.

Although we think this is a plausible account, it is, of course, speculation. Many other pressures may have contributed to the evolution of human foresight and threat management. For instance, increasing cooperation itself harbours numerous powerful threats (Tomasello, Melis, Tennie, Wyman, & Herrmann, 2012). Failing to detect cheaters, negative appraisal from a social dominant and attacks from other organised groups, are just some of the many threats borne of human hypersociality (Braxton, 2009; Emery, Seed, von Bayern, & Clayton, 2007). Some of these threats may have been pivotal in driving the evolution of a new kind of cognitive representational system, one flexible enough to represent the minds of conspecifics as well as their past - and possible future - behaviours (Sterelny, 2003). Accordingly, the threats posed by other humans in early social groups potentially shaped and fine-tuned the evolution of complex cognitive capacities to enable the mapping of the social world and subsequent prediction of conspecific action (Nesse, 2009; Sznycer et al., 2016; Trower & Gilbert, 1989). Suffice it to say that plausibility should not be mistaken as proof. We suspect that many factors dynamically interacted in forging these modern capacities.

**4.7. Further directions and remaining questions**

We offer a number of proposals for future research in this area based on each of Tinbergen’s four questions (1963) for comprehensively addressing the nature of a trait (see also Mayr, 1961). In so doing, we hope to encourage cross-disciplinary consideration of both proximate and ultimate explanations for internally generated cognition more broadly, considering an important goal of the life sciences should be to integrate these levels of analysis to provide a comprehensive account of a phenomenon (see Scott-Phillips et al., 2011). In some cases the answer to the following questions would provide direct empirical support for, or falsification of, the ideas presented in this paper.

#### 4.7.1. Phylogeny

Humans may be unique in their capacity to imagine past and future threat narratives without immediately perceptible cues (Miloyan, Bulley, et al., 2016). This does not mean that other animals may not be capable of representing threats with some kind of memory trace or mental imagery (Barsalou, 1999; S. Cheng et al., 2016; Gardenfors, 1995; Osvath & Gärdenfors, 2005), but with the caveat that only humans may *know* that they are remembering or imagining that threat (Redshaw, 2014). With a better understanding of whether, and if so which, other species share some of these capacities, their evolution can be reconstructed (Suddendorf, 2013). Indeed, the capacities and limits of non-human animal memory and prospection are the focus of on-going debate (Cheke & Clayton, 2010; Osvath & Martin-Ordas, 2014; Raby & Clayton, 2009; Scarf, Smith, & Stuart, 2014; Suddendorf & Corballis, 2010; Thom & Clayton, 2016). However, while most previous research has focussed on how non-human animals remember or plan for rewards, to date very little research has examined animal performance in similar tasks when subjects must remember or prepare for threats. This is important because threats to reproductive fitness likely played a critical role in the evolution of predictive cognitive processes more generally (Mobbs et al., 2015), and, as we have suggested here, it is possible that preparation for threats may have been a potent selective pressure in the evolution of complex memory and prospection. There are obvious ethical roadblocks, however, that may explain why this has gone understudied.

#### 4.7.2. Adaptive significance

Anxiety disorders can be conceptualised as extreme values at the high tail end of a distribution of the adaptive underlying trait. The other extreme, lack of anxiety, generally goes unreported because it is not usually associated with distress but may nonetheless be maladaptive because it prevents adequate precautionary behaviour in the face of danger (Marks & Nesse, 1994). This generates questions about what an ‘adaptive’ or ‘functional’ range of threat-related internally-generated thinking might be (Perkins et al., 2015). An evolutionary perspective on threat-related internally generated thinking cannot consider these processes entirely maladaptive despite the costs they entail (Brüne, 2006, 2008; Del Giudice, 2014). In this regard, Nesse (1979) notes that: “If a drug were found that abolished all anxiety for all time it could be as harmful as a drug that induced anxiety of crippling degree". These questions will undoubtedly have a different answer depending on whether they are posed about the environments in which the trait evolved, or in contemporary societies[2] (P. Bateson & Laland, 2013). One avenue into the 'current utility' question might be to look for associations between scores on a modified threat-related autobiographical memory/ prospection interview (see Levine, Svoboda, Hay, Winocur, & Moscovitch, 2002) and real world mortality and reproductive outcomes. For instance, might the imagery vividness with which people can foresee prospective threats be associated with reduced accident-related mortality?

#### 4.7.3. Proximate mechanisms

As a threat becomes physically closer in space, the processing of defensive reactions in neural circuitry undergoes a shift from more frontal regions (e.g. ventromedial prefrontal cortex) to more midbrain and brainstem regions (e.g. periaqueductal gray) (Mobbs et al., 2009; Mobbs, Petrovic, Marchant, Hassabis, & Weiskopf, 2007). It remains to be seen if there is a *temporal* threat proximity analogue to this process, and if so whether it is subserved by similar neural structures. In fact, the spatial proximity studies could be construed in temporal terms, though no work to our knowledge has attempted to tease these apart (see also Trope & Liberman, 2010). This is relevant because, as we have outlined in this paper, different cognitive and neural processes are involved in inferring a threat *without* directly perceptible cues compared to when these cues are available in the immediate environment.

#### 4.7.4. Development

Approaches drawn from developmental or lifespan psychology may prove informative given that large changes are observed in anxiety symptomology and processes through childhood and the adult lifespan, often in different ways depending on the anxiety subtype (Miloyan & Bulley, 2016; Miloyan, Bulley, Pachana, & Byrne, 2014; Miloyan, Byrne, & Pachana, 2014; Waters et al., 2008). There is also solid theoretical rationale based in behavioural ecology about how anxiety (and hence threat-related internally generated thinking) will change based on developmental stages in childhood, as well as some evidence to corroborate these predictions (for review see Boyer & Bergstrom, 2011; Marks & Nesse, 1994). While there is an increasing appreciation of the

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[2] Note that a separate, non-evolutionary question along these lines can also be posed about human wellbeing rather than reproductive success.

developmental milestones underpinning episodic processes in children (for reviews see Martin-Ordas et al., 2014; Suddendorf & Redshaw, 2013), little is known about age-related changes to the internally generated representation of threat across the lifespan despite some recent attempts to address this phenomenon in the context of clinical anxiety in older adulthood (for review see Miloyan, Pachana, et al., 2016). For example, because older adults consistently generate fewer episodic relative to semantic details when remembering the past or imagining the future, the nature of their cognitive threat representations should shift towards semantic processing, and thereby account for some of the characteristic worry patterns observed in this age group (Miloyan & Bulley, 2016).

### 4.8. Concluding remarks

A capacity for internally generated cognition in humans enables the spatiotemporally detached representation of threats, thereby extending the functionality of threat-detection and threat-management farther into the future. We have presented a taxonomy of this threat-related internally generated cognition comprising memory and prospection in both semantic and episodic formats. Each of the processes in this taxonomy may contribute to the same adaptive end-goal of threat-management, but via different proximate mechanisms. Phylogenetically novel cognitive capacities such as mental time travel may be responsible for the rapid, efficient and complex manner in which humans can detect and respond to potential threats lurking even in the distant future. However, because this means threat detection can be engaged even without immediate cues of danger, these capacities may also account to a large degree for the protracted and deleterious nature of anxiety disorders in contemporary humans. Nonetheless, a species capable of both abstracted and narrative mental representations of threats, past and future, attains a powerful advantage in managing potential dangers moving forward. Internally generated thinking about threats, not restrained solely to cues in the external environment, opens wider the temporal window between the present moment and future dangers, affording valuable time for avoidance or preparation.

## Chapter Five. Death and decision-making: Life expectancy and intertemporal choice

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**Preface and details of contribution to authorship:**

This chapter presents the results from a cross-country test of the role of threat in intertemporal decision-making. The findings support predictions from previous chapters about the role of danger in encouraging preferences for immediate relative to delayed outcomes. It extends this concept into the domain of reproductive decision-making (age of first birth). I conceived the study as well as compiled and analysed the data with Gillian Pepper. I wrote the first draft and finalised the paper after critical revisions from Gillian Pepper.

**Abstract**

Humans, like other animals, typically discount the value of delayed rewards relative to those available in the present. From an evolutionary perspective, prioritising immediate rewards is a predictable response to high local mortality rates, as is an acceleration of reproductive scheduling. In a sample of 46 countries, we explored the cross-country relationships between average life expectancy, intertemporal choice, and women's age at first birth. We find that, across countries, lower life expectancy is associated with both a smaller percentage of people willing to wait for a larger but delayed reward, as well as a younger age at first birth. These results, which hold when controlling for region and economic pressure (GDP-per capita), dovetail with findings at the individual level to suggest that life expectancy is an important ecological predictor of both intertemporal and reproductive decision-making.

## 5.1. Introduction

Humans, like other animals, typically discount the subjective value of delayed rewards relative to those available in the present (Berns et al., 2007). Explanations for this *delay discounting* phenomenon tend to emphasize that the uncertainty of future rewards makes capitalising on immediate opportunities a beneficial strategy in many circumstances (Andreoni & Sprenger, 2012; Daly & Wilson, 2005; Stevens & Stephens, 2010). Indeed, *intertemporal choices* between immediate and delayed rewards are highly sensitive to context in humans (Lempert & Phelps, 2015). One common prediction about the role of ecological context, grounded in evolutionary theorising, is that intertemporal decision-making should on average shift towards immediate rewards when local mortality rates are high (e.g. Daly & Wilson, 2005; Frankenhuis, Panchanathan, & Nettle, 2016; E. M. Hill et al., 2008; Kruger & Zimmerman, 2008). This is because a higher mortality risk equates to a lower likelihood of capitalising on delayed rewards due to the possibility of death. This is expected to take place both for an individual who may come to change their decision-making based on exposure to relevant information in their environment, but also at the group level whereby shared ecological factors like higher local mortality rates should produce on average steeper delay discounting.

Various lines of evidence support this proposition at the individual psychological level, including findings that exposure to natural disasters, violence or mortality cues is associated with a preference for immediate rewards over delayed ones (Lahav et al., 2011; Li et al., 2012; Pepper & Nettle, 2013; Ramos, Victor, Seidl-de-Moura, & Daly, 2013). Thus far, the evidence on this front comes from between- or within-participant analyses within the same country (e.g. Ramos et al., 2013), and analyses have tended to focus on specific cues of mortality risk, such as exposure to violence, rather than local mortality rates more generally. Here we therefore extend this work by asking whether variation in life expectancy across countries acts as an ecological predictor of the average intertemporal decision-making in those countries.

A similar logic applies in the domain of reproductive scheduling (Chisholm, 1993; Nettle, 2011; M. Wilson & Daly, 1997). As local mortality risk increases, people are expected to reproduce earlier, and to produce more offspring throughout their reproductive careers (Charnov, 1991; Ellis, Figueredo, Brumbach, & Schlomer, 2009; Roff & Stearns, 1991). The benefits of accelerated reproductive scheduling when mortality risk is high are thought to arise from both an increased chance of reproducing, and increased time available to care for offspring, before death. There is evidence that both within and between countries, women's average age at first birth is younger when mortality rates are higher (Low, Hazel, Parker, & Welch, 2008). Local mortality risk indicators also predict total fertility, such that people in higher mortality-risk conditions tend to have more children on average throughout the lifespan (Guégan, Thomas, Hochberg, de Meeus, & Renaud, 2001; J. Zhang & Zhang, 2005). We therefore sought to also replicate these previously reported relationships between life expectancy and age at first birth. Steeper temporal discounting has also been associated with having more sexual partners, an earlier age of first sexual activity, more relationship infidelity, greater odds of having a past or current pregnancy, and lower contraceptive use (Chesson et al., 2006; McCoul & Haslam, 2001; Reimers, Maylor, Stewart, & Chater, 2009). However it has thus far gone unexamined how average intertemporal decision-making patterns relate to reproductive scheduling patterns across different ecologies.

The current study therefore had two main aims. Firstly, we aimed to explore the relationship between life expectancy, and both intertemporal choice and age at first birth. Secondly, we aimed to explore the association between intertemporal choice and age at first birth. We hypothesized that, across countries, (i) lower average life expectancy would be associated with a lower percentage of people willing to wait for a larger later reward, (ii) lower average life expectancy would be associated with younger age at first birth, as found in prior studies, and (iii) a lower percentage of people willing to wait for a larger later reward would be associated with younger average age at first birth.

## 5.2. Method

### 5.2.1. Measures

***5.2.1.1. Intertemporal choice.*** Intertemporal choice data were collected as a single binary choice item in the International Test of Risk Attitudes (INTRA) survey conducted by the University of Zurich and made publicly available in a recent publication (Wang, Rieger, & Hens, 2016). The average age of participants was 21.5 years (SD = 3.77), and 52.5% of the participants were males (for more details see Wang, Rieger, & Hens, 2016). Participants were asked to indicate whether they would prefer: (A) a payment of $3400 this month; or (B) a payment of $3800 next month (from Frederick, 2005). Participants were university students (mostly in the departments of economics, finance, and business administration) and the monetary amounts in the choice question were adjusted according to the Purchasing Power Parity and monthly income and expenses of the students in each country. The sample contained intertemporal choice data from 6901 participants from 53 countries. These responses were used to calculate the percentage of respondents from each country who chose the delayed but larger reward. More details about the methodology of the INTRA survey are available from Wang et al., (2016) and Rieger et al., (2015).

***5.2.1.2. GDP-PC, life expectancy, age at first birth and region.*** Data on gross domestic product per capita (GDP-PC) and life expectancy for 52 of the 53 countries for which intertemporal choice data were available from the World Bank open data bank available online (United Nations, 2010). INTRA survey data on percentage of people willing to wait were available for Taiwan, but GDP-PC, life expectancy and age at first birth data were not. Therefore, Taiwan was not included in our analyses. Data on age at first birth were available from the CIA World Fact Book online (CIA, 2016). Age at first birth data were not available for Argentina, Chile, China, Lebanon, Malaysia, or Vietnam, leaving complete data for 46 countries. Because the INTRA data on intertemporal choice were collected over a number of years (between 2007-2012), GDP-PC and life expectancy data were averaged over the years during which the intertemporal choice data were collected in each country (details of the years during which data were collected were provided by Wang et al. in correspondence, and can be seen in the data provided as an electronic supplement). The available data on age at first birth lacked the same level of temporal specificity, and were instead collected at various time-points ranging from 2006 to 2012.

GDP-PC was measured in USD, and is defined by the World Bank as "gross domestic product divided by midyear population". The World Bank defines GDP as "the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources." Life expectancy, another World Bank indicator, is defined as: "the number of years a newborn infant would live if prevailing patterns of mortality at the time of its birth were to stay the same throughout its life". Age at first birth, as defined by the CIA world fact book, represents: "the mother's mean age at first birth" for a given country. Region classifications were assigned as per the World Bank's "Country and Lending Groups" classifications, available online.

### 5.2.2. Data analysis

Hypotheses, measures, and our analytical plan were pre-registered with the Open Science Framework: https://osf.io/yu2hs/.[3] All statistical analyses were performed in R studio (R Core Team, 2008). We created a series of linear mixed models to address each hypothesis, with a random intercept of 'region' to control for the potential non-independence of the sample countries due to shared features such as climate and cultural histories, using *lme4* (Bates, Mächler, Bolker, & Walker, 2015). The sample sizes obtained in the INTRA survey varied by country (range = 38-540, Wang et al., 2016). Analyses were therefore weighted for the sample size of the intertemporal choice data. All predictors were standardised in order to deal with the scale differences between GDP-PC and the other predictor variables. Plots were created with *ggplot2* (Wickham, 2009) and *ggrepel* (Slowikowski, 2016). We also used the *dplyr* (Wickham, 2016) and *psych* (Revelle, 2015) packages to organise the data and generate descriptive statistics. The R script used for analysis is available as an electronic supplement to this paper, as is the dataset and an information sheet about the included variables. As part of our electronic supplement, we have also created maps to visualise the cross-country variation in life expectancy (available online, here), intertemporal choice (available here), and age at first birth (available here).

## 5.3. Results

### 5.3.1. Descriptive statistics

Descriptive statistics for the percentage of people willing to wait, GDP-PC, life expectancy and age at first birth are available in Table 5.1. As might be expected, countries with a higher GDP-PC tended to have longer life expectancies ($X^2(1) = 33.33$, $p < 0.001$, $\beta = 3.13$, s.e. = 0.45).

[3] Changes to the pre-registered analytical plan were as follows: Firstly, due to a serious lack of adherence to statistical assumptions, models with the 'fertility' variable were removed from our final analyses. Subsequently, we generated new hypotheses about age at first birth and included analyses to test these hypotheses after failing to fit adequate models with the fertility data. Finally, we removed the planned mediation analysis due to concerns about testing for individual-level psychological mechanisms using country-level data (the ecological fallacy; see Kuppens & Pollet, 2014), and employed linear mixed models with a random effect of region instead of standard linear models.

**Table 5.1.** Descriptive statistics for the main study variables

| | Mean | SD | Min | Max | Range | n |
|---|---|---|---|---|---|---|
| Percentage willing to wait | 0.63 | 0.18 | 0.08 | 0.89 | 0.81 | 52 |
| GDP-PC | 27852.22 | 24939.17 | 657.73 | 113239.56 | 112581.83 | 52 |
| Age at first birth | 26.84 | 3.42 | 19.4 | 31.2 | 11.8 | 46 |
| Life expectancy | 75.89 | 7.02 | 49.85 | 82.51 | 32.66 | 52 |

### 5.3.2. Relationship between life expectancy and intertemporal choice

We conducted a linear mixed effects analysis of the relationship between life expectancy and intertemporal choice, controlling for GDP-PC and a random effect of geographic region. As fixed effects, we entered GDP-PC and life expectancy, and as a random effect we included a random intercept of region. We obtained *p*-values by running likelihood ratio tests, using the drop1 function (Burke, 2011) to compare the fit of the full model with those of models with each predictor removed. Results revealed a relationship between life expectancy and intertemporal choice ($X^2(1) = 9.88$, $p < 0.01$), such that a higher life expectancy was associated with a higher percentage of people willing to wait for the larger, later reward on average ($\beta = 0.09$, s.e. = 0.03, Figure 5.1, Table 5.2). Thus, people in countries with a shorter average life expectancy tended to be less willing on average to wait for the delayed reward. Note that results of a similar model excluding life expectancy revealed a relationship between GDP-PC and intertemporal choice ($X^2(1) = 17.99$, $p < 0.001$), such that a greater GDP-PC was associated with a higher percentage of people willing to wait for the larger, later reward on average ($\beta = 0.1$, s.e. = 0.02). However, this effect of GDP-PC on intertemporal choice was attenuated when life expectancy is included in the model (Table 5.2).

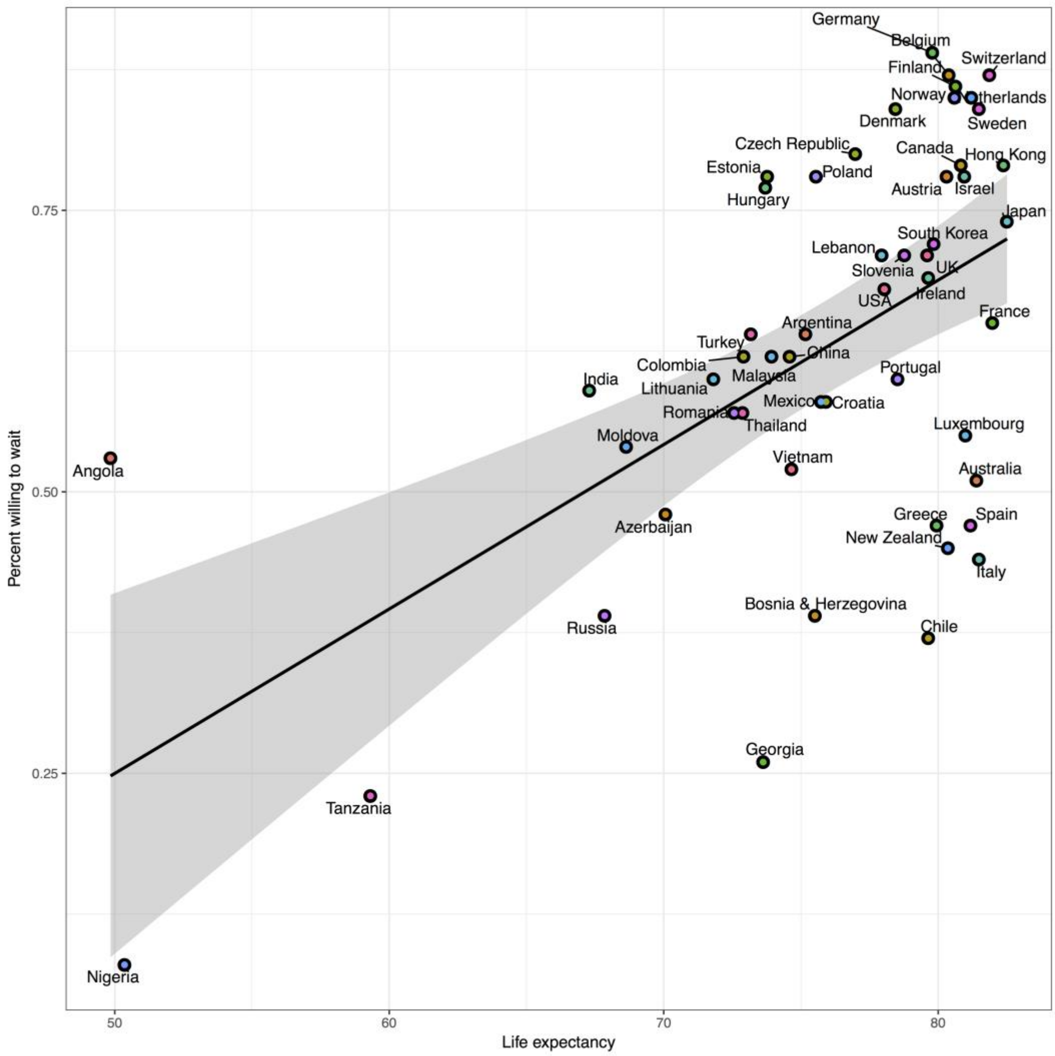



*Figure 5.1.* Relationship between average life expectancy across countries and the percentage of people willing to wait for a larger later reward: r = 0.57, p <0.001

**Table 5.2.** Results of the full mixed effects model predicting intertemporal choice with GDP-PC and life expectancy, with a random effect of region. P-values derived from LRTs.

| | **Intertemporal choice** | | |
|---|---|---|---|
| **Fixed effects** | **β** | **SE** | **p** |
| GDP-PC | 0.05 | 0.02 | 0.06 |
| Life expectancy | 0.09 | 0.03 | <0.01 |
| | | | |
| **Random effects** | **Variance** | **SD** | |
| Region (intercept) | 0.00 | 0.00 | |
| Residual | 2.09 | 1.45 | |
| | | | |
| **AIC** | -46.9 | | |
| **N (countries)** | 52 | | |

### 5.3.3. Relationships between life expectancy, intertemporal choice, and age at first birth

We conducted linear mixed effects analyses of the relationships between life expectancy, intertemporal choice and age at first birth, controlling for GDP-PC and a random effect of geographic region. Again, we compared models with likelihood ratio tests using the drop1 function (Burke, 2011).

Results revealed a relationship between life expectancy and age at first birth ($X^2(1) = 16.77$, $p < 0.01$, Table 5.2) after controlling for GDP-PC, intertemporal choice, and region, such that a lower life expectancy was associated with a younger age at first birth, in line with prior findings (e.g. Low et al., 2008; β = 2.32, s.e. = 0.52, Figure 5.2). We found no relationship between intertemporal choice and age at first birth after controlling for GDP-PC, life expectancy and region ($X^2(1) = 0.34$, $p = 0.56$, Table 5.3), even though this relationship was seen before controlling for these variables ($r = 0.50$, $p < 0.001$, Figure 5.3), and was a significant predictor in a model controlling for GDP-PC and region, but not life expectancy ($X^2(1) = 4.11$, $p = 0.04$).

**Table 5.3.** Results of the full mixed effects model predicting age at first birth with intertemporal choice, GDP-PC and life expectancy, with a random effect of region.

| | Age at first birth | | |
|---|---|---|---|
| **Fixed effects** | **β** | **SE** | **p** |
| GDP-PC | 0.61 | 0.35 | 0.10 |
| Life expectancy | 2.32 | 0.52 | <0.001 |
| Intertemporal choice | 0.19 | 0.33 | 0.56 |
| **Random effects** | **Variance** | **SD** | |
| Region (intercept) | 2.77 | 1.67 | |
| Residual | 297.53 | 17.25 | |
| **AIC** | 200.1 | | |
| **N (countries)** | 46 | | |

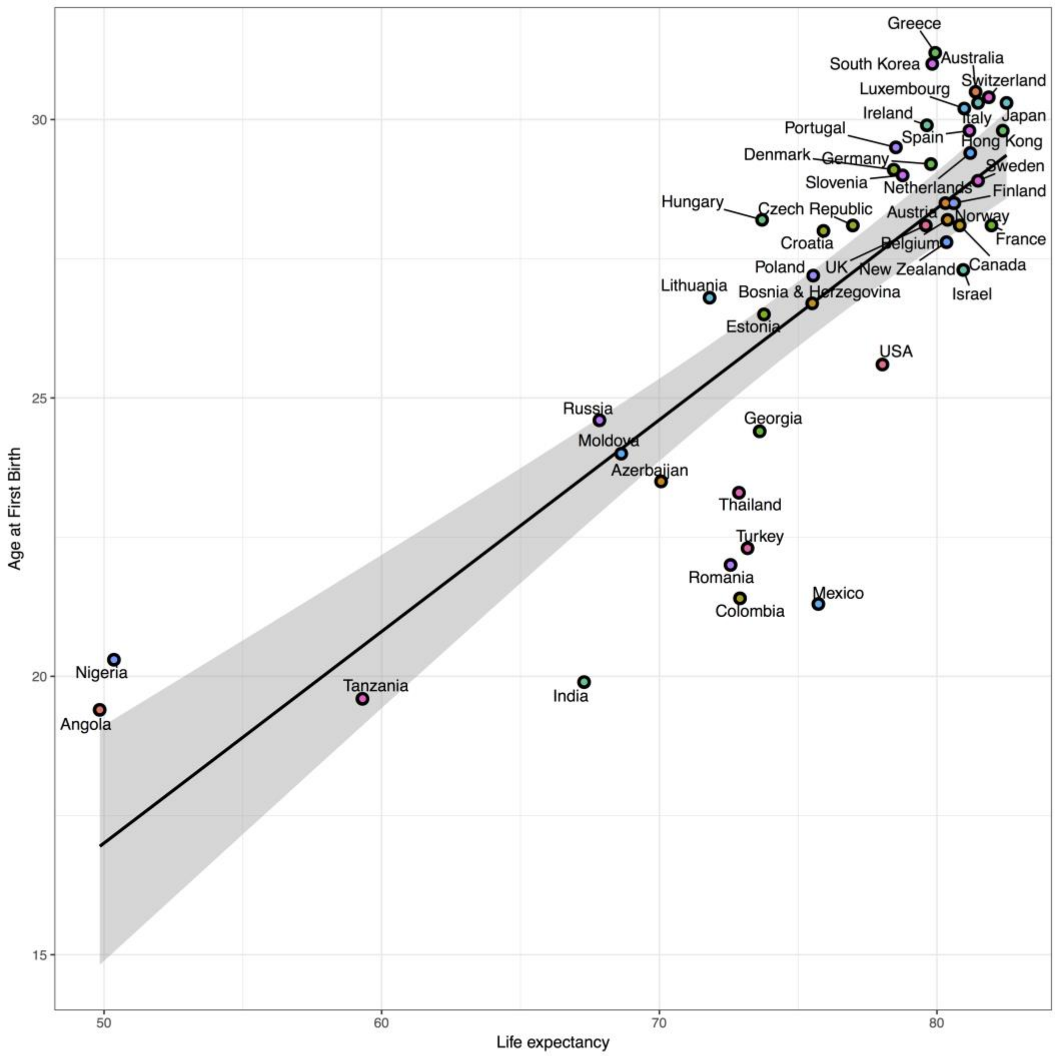



*Figure 5.2.* Relationship between average life expectancy across countries and average age at first birth: $r = 0.83$, $p < 0.001$

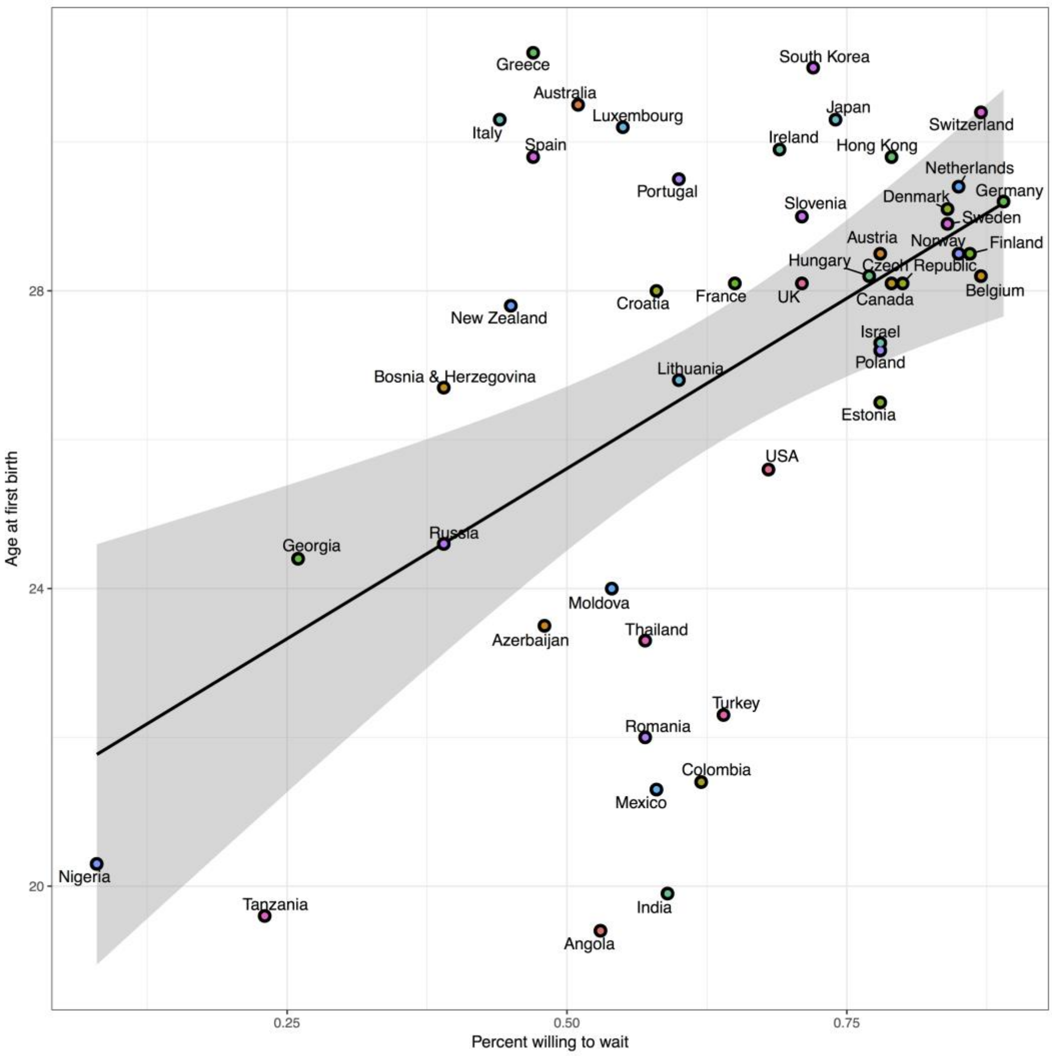



*Figure 5.3.* Relationship between the percentage of people willing to wait for a larger later reward and average age at first birth across countries: $r = 0.50$, $p < 0.001$

## 5.4. Discussion

We tested associations between life expectancy, intertemporal choice, and age at first birth in a cross-sectional sample of 46 countries. We predicted that, across countries: (i) lower life expectancy would be associated with fewer people willing to wait for a larger later reward; (ii) in line with prior findings, lower life expectancy would be associated with younger age at first birth; and (iii) a lower percentage of people willing to wait for a larger later reward would be associated with younger age at first birth. Results support these hypotheses, with the relationships remaining significant even after controlling for region and general wealth (GDP-PC). However, the percentage of people willing to wait was no longer a predictor of age at first birth when life expectancy was included in the model. Thus, hypothesis (iii) is likely only supported because life expectancy is associated with both willingness to wait, and with age at first birth, rather than because willingness to wait affects age at first birth directly.

This is the first study, to our knowledge, to examine the cross-country level association between life expectancy and intertemporal choice. The results dovetail with findings at the individual level, which suggest that people whose experiences seem indicative of a limited life expectancy tend to discount future rewards more steeply (e.g. Lahav, Benzion, & Shavit, 2011; Li et al., 2012; Pepper & Nettle, 2013). However, while these similar findings at the individual level are suggestive of the possibility that people might adjust their intertemporal choice to accord with local mortality rates, the current results also reveal life expectancy itself to be an important ecological predictor of intertemporal choice on aggregate. Further studies will be needed at the individual level to determine if individual life expectancy predicts intertemporal decision-making in a similar way. Because intertemporal choice is associated with health-related behaviour and outcomes (Story et al., 2014), as well as people's beliefs (Shenhav, Rand, & Greene, 2016) and economic behaviours (Falk et al., 2015), identifying ecological variables that predict aggregate intertemporal decision-making may be useful to public health specialists and other professionals aiming to improve outcomes predicted by intertemporal choice. For example, developing a reliable account of the factors which predict health investment by accounting for various ecological predictors would enable those creating health campaigns to target those areas where potentially deleterious decision-making patterns are most likely to emerge.

Given the cross-sectional nature of our data, we cannot confirm that the associations we have reported are causal. Neither can the direction of any causal association be discerned. This leaves open at least two possible explanations for the observed association between life expectancy and intertemporal choice. Firstly, it is possible that ecological conditions giving rise to lower life expectancy lead to a greater preference for immediate rewards. In line with a number of theoretical perspectives from human behavioural ecology and evolutionary psychology, people may shift their intertemporal decision-making towards immediate rewards in countries with higher mortality risk (e.g. Daly & Wilson, 2005). Our results do not speak to the phylogenetic, developmental or psychological mechanisms that might underpin this shift, though recent works have highlighted some plausible (and potentially intersecting) proximate accounts including developmental plasticity (Frankenhuis et al., 2016), implicit adjustment on the basis of external cues (Pepper & Nettle, 2013) and explicit mental reasoning or planning (Bulley, Henry, et al., 2016).

Another, non-mutually exclusive explanation for the relationship between life expectancy and intertemporal choice is that a greater preference for immediate rewards in intertemporal choice leads to lower life expectancy by decreasing efforts to protect future health. Increased delay discounting has been associated with a host of poorer health behaviours and outcomes (for a review see Story, Vlaev, Seymour, Darzi, & Dolan, 2014). If the relationship observed in this study runs in both of the aforementioned directions, then we can speculate about the feedback loops that might be generated. Specifically, if cues signifying unavoidable mortality risk lead to increased temporal discounting and decreased health-promoting behaviour, thereby lowering life expectancy, then a feedback loop may be initiated: with lower life expectancy causing greater temporal discounting and a disinvestment in future health, which in its turn reiterates the cycle (Gibson & Lawson, 2014; Griskevicius et al., 2011; Nettle, 2010b; Pepper & Nettle, 2013, 2017).

The current results also replicate a previously observed relationship between life expectancy and age at first birth, such that lower life expectancy was associated with a younger age at first birth. Similar findings have previously been reported both between and within countries (Bulled & Sosis, 2010; Low et al., 2008; Low, Parker, Hazel, & Welch, 2013; Nettle, 2010a; Quinlan, 2010; M. Wilson & Daly, 1997). The prevailing explanation for this association in evolutionary terms is that as local mortality rates increase, people adopt accelerated reproductive scheduling in order to maximise their potential investment in offspring. An earlier age at first birth is predicted to be adaptive when life expectancy is lower because this increases both the chances of reproducing and the length of time available to care for offspring before death (Chisholm, 1993; see Harvey & Zammuto, 1985 for an analogous cross-species pattern). Investing resources in offspring is ostensibly a more adaptive strategy when extrinsic (uncontrollable) mortality risks are low. For more on the relevant trade-offs inherent to reproductive scheduling and decision-making, see (E. M. Hill, Ross, & Low, 1997; Low, 2015; M. Wilson & Daly, 1997).

Our results also showed a correlation between intertemporal choice and age at first birth, such that a higher percentage of people willing to wait for a larger later reward was associated with a lower age at first birth across countries. It is likely that this relationship manifests because both intertemporal choice and age at first birth are associated with life expectancy. Indeed, intertemporal choice was no longer a significant predictor of age at first birth after controlling for life expectancy, suggesting that decision-making in financial and reproductive domains might be associated via different mechanisms.

Although we included GDP-PC in our analyses primarily as a control variable, it is interesting to note that the effect of GDP-PC on intertemporal choice is attenuated when life expectancy is added to the model (Table 5.2). This suggests that a portion of the effect of GDP-PC on intertemporal choice may be accounted for by the fact that higher GDP-PC countries tend to have longer life expectancies. It is often assumed that the drivers of intertemporal choice are more economic or endogenous than ecological. However, a meaningful portion of the effect of economic variables such as wealth (at either individual or national level) on intertemporal choice may be exerted indirectly via the effects of wealth on ecological factors such as life expectancy.

There are a number of limitations to the current study that should be noted. Firstly, although there have been similar findings at the individual level, as discussed above, (Griskevicius et al., 2011; Pepper & Nettle, 2013; Quinlan, 2010; Rodgers, St John, & Coleman, 2005), the present analyses utilise aggregated cross-country level data, making any interpretations thereof prone to the ecological fallacy (Kuppens & Pollet, 2014; Robinson, 2011). For this reason, we must be cautious of interpreting the results as if they refer to individual level processes, and instead recognise the utility of the revealed cross-country level relationships in their own right. It will be important for future research to probe these associations, and to extend them at the individual level, with experimental studies better placed to discern causality in these domains (e.g. McAllister, Pepper, Virgo, & Coall, 2016).

Secondly, the economic characteristics of the countries in our sample were relatively restricted. Specifically, the sample contained very few countries with lower GDP-PCs and life expectancies. Thus, while cross-country data on intertemporal preferences are difficult to collect, future studies should focus on countries at the lower end of the GDP-PC and life expectancy continua. Thirdly, the intertemporal choice data from within each country were not nationally representative, being instead comprised of college student samples (see Wang et al., 2016 for details and additional consideration of the limitations of this data). These samples most likely represented populations that were relatively more educated and affluent than the country average. Given that such affluence and education have been linked to increased patience (Haushofer & Fehr, 2014), the data may underestimate the true levels of discounting in each country. With that said, the samples are biased in a similar manner across countries, meaning that the differences between countries are still informative.

Fourthly, the intertemporal choice measure employed in the current study simply represented the percentage of people in the sample from each country that indicated they were willing to wait for a larger later reward over an immediately available one. The survey item by which this data was collected is a single-shot intertemporal choice question, confirmed by subsequent questions designed to measure the discount rate over longer periods (1 year, and 10 years). The measure is thus unlikely to provide the same precision as a full intertemporal choice questionnaire such as the Kirby discounting survey, which enables the calculation of a temporal discounting index such as 'area under the curve' (Kirby, Petry, & Bickel, 1999). Nonetheless, one-shot intertemporal choice questions have been shown to have significant predictive power in relevant domains such as age of first sexual activity, and appear to give similar results to more traditional adjusting-amount procedures for fitting discounting functions (Reimers et al., 2009). Finally, it is worth noting that there are a large number variables that were not included in our models, including, for example, the quality of education in each country, that probably play a role in the observed relationships.

This study provides the first examination, to our knowledge, of a cross-country level association between life expectancy and intertemporal choice. Across 52 countries, we find that lower life expectancy is associated with a lower percentage of people willing to wait for a larger, later reward. In line with previous studies, our results also show that a lower average life expectancy is associated with an earlier average age at first birth. Finally, we find that a lower percentage of people willing to wait for a delayed reward is associated with a younger average age at first birth across a subsample of 46 countries. These relationships all held true after controlling for GDP-PC and region. However, the relationship between intertemporal choice and age at first birth was not significant when controlling for life expectancy indicating that, although life expectancy is associated with both intertemporal choice and age at first birth, intertemporal choice may not influence age at first birth directly.

Our results dovetail with a body of research at the individual and cross-country level that suggests people adjust their intertemporal and reproductive scheduling decisions on the basis of relevant environmental variables, including local mortality risk. The results are also in line with findings that accentuated temporal discounting is associated with a host of poorer health behaviours and outcomes, which may result in a reduced life expectancy. They suggest that life expectancy is an important predictor of intertemporal and reproductive decision-making at the aggregate level, making it worthy of further investigation.

## Chapter Six. Look before you leap: Episodic foresight, delay discounting and risk taking

**Bulley, A.,** Miloyan, B., Pepper, G.V. Gullo, M. J., Henry, J.D., & Suddendorf, T. (Submitted) Cuing both positive and negative episodic foresight reduces delay discounting but does not affect risk taking. *The Quarterly Journal of Experimental Psychology.*

### Preface and details of contribution to authorship:

Cross-country analyses are difficult to interpret. This chapter presents the results of a large-scale experimental investigation that was therefore conducted into the role of both cued threat-related and positive episodic foresight on impulsivity in the domains of intertemporal choice and risk taking. The results are in line with predictions made previously about the role of positive episodic foresight in intertemporal choice, but are not in line with hypotheses about the role of threat-related foresight. I conceived the idea with Beyon Miloyan, collected and analyzed all data, wrote the first draft, and finalized the paper. All other authors gave critical input into the design of the experiment. Beyon Miloyan, Gillian Pepper, and Thomas Suddendorf helped devise the specific analytical strategy. All authors helped write the paper.

**Abstract**

Humans frequently create mental models of the future, allowing outcomes to be inferred in advance of their occurrence. Recent evidence suggests that imagining positive future events reduces delay discounting (the devaluation of reward with time until its receipt), while imagining negative future events may increase it. Here, using a sample of 297 participants, we experimentally assess the effects of cued episodic simulation of positive and negative future scenarios on decision-making in the context of both delay discounting (monetary choice questionnaire) and risk-taking (balloon-analogue risk task). Participants discounted the future less when cued to imagine positive and negative future scenarios than they did when cued to engage in control neutral imagery. There were no effects of experimental condition on risk-taking. Thus, although these results replicate previous findings suggesting episodic future simulation can reduce delay discounting, they indicate that this effect is not dependent on the valence of the thoughts and does not generalise to all other forms of 'impulsive' decision-making. We discuss various interpretations of these results and suggest avenues for further research on the role of prospection in decision-making.

## 6.1. Introduction

Humans have the capacity to simulate potential future events and to organise behaviour accordingly. This capacity has been called 'episodic foresight' or 'episodic future thinking' (Atance & O'Neill, 2001; Schacter et al., 2017; Suddendorf & Moore, 2011; Szpunar & Radvansky, 2015), and it is of enormous functional significance because it enables people to plan and prepare for anticipated future possibilities (Pezzulo, 2016; Suddendorf, Bulley, & Miloyan, 2018; Suddendorf & Corballis, 2007). Many different aspects of decision-making involve accounting for such possible future circumstances, including intertemporal choices – in which sooner and later outcomes are pitted against one another (Berns et al., 2007).

### 6.1.1. Intertemporal choice and episodic foresight

Many decisions have consequences that emerge only after a delay, and these delayed outcomes may be, to varying degrees, integrated into decision-making mechanisms (Peters & Büchel, 2011; Story et al., 2013). Nonetheless, humans have a strong tendency to discount the value of future rewards relative to ones that are immediately available (Berns et al., 2007). This tendency for *delay discounting* varies substantially as a trait between people (Peters & Büchel, 2011) due to factors such as genetic heritability (Anokhin et al., 2011; Sanchez-Roige et al., 2018), and various aspects of developmental history or current environmental characteristics (Pepper & Nettle, 2017). As a somewhat distinct aspect of impulsivity – sometimes called *choice impulsivity* (Dawe, Gullo, & Loxton, 2004; Gullo, Loxton, & Dawe, 2014; Hamilton et al., 2015) – delay discounting in humans is perhaps best considered an index of people's *preferences* for smaller, sooner rewards relative to larger delayed rewards when those rewards are in opposition. This is reflected in the measurement of the delay discounting construct, in which the standard instruments require participants to make forced choices between smaller but sooner and larger but later monetary amounts (e.g. Kirby et al., 1999). However, observable delay discounting also varies within individuals (Lempert & Phelps, 2015) based on the framing of the choice question, current mood state, other contextual variables, and ongoing cognitions (Berns et al., 2007). It stands to reason that ongoing prospective cognition focussed on the future might be particularly important in determining the prioritisation of delayed relative to more immediate rewards.

Indeed, various lines of evidence have emerged recently to suggest that cueing episodic foresight can be sufficient to encourage preferences for larger, later rewards in intertemporal choice tasks (for reviews see Bulley, Henry, et al., 2016; Schacter et al., 2017). In the first empirical studies on this topic, spurred by a theoretical article by Boyer (2008), participants completed modified intertemporal choice tasks to assess their preferences whilst simultaneously imagining personally relevant future events and undergoing fMRI scans. In Peters and Büchel's (2010) study, participants made a series of choices, for instance between 20€ now and 35€ in 45 days, while being cued with an actual event they had planned for in around 45 days' time. In the episodic cue condition, preferences shifted towards delayed rewards. A subsequent study observed a similar pattern of results (Benoit et al., 2011). The authors of these first studies suggested that the effect of episodic foresight on intertemporal choice was linked to a neural mechanism of functional connectivity between brain regions in the core network involved in episodic simulation and prefrontal hubs involved in valuation.

Since those first investigations, associations between imagining the future and intertemporal decision-making have been reported in many other studies, and links have been reported to various other decision-making profiles and behaviours that collectively fall under the umbrella of "impulsivity". For instance, cuing participants to imagine the future has been shown to reduce ad-libitum calorie intake in obese women and children (Daniel 2015, 2013), as well as healthy undergraduate women (Dassen 2016). Such cueing has also been shown to reduce hypothetical alcohol demand in alcohol dependent people (Snider 2016) and undergraduates (Bulley & Gullo, 2017). However, in both of these latter studies the effects were somewhat selective; affecting certain alcohol purchase demand indices, but not others. Similar effects have been reported in the context of the intensity of cigarette demand (J. S. Stein, Tegge, Turner, & Bickel, 2017) and actual cigarette smoking among samples of smokers (J. S. Stein et al., 2016).

Given that delay discounting itself has been linked to a range of negative behaviours and outcomes from obesity (Amlung, Petker, Jackson, Balodis, & Mackillop, 2016), to gambling (MacKillop et al., 2011; Wiehler & Peters, 2015), to lower life expectancy (Bulley & Pepper, 2017) – and is therefore considered an important trans-disease process (Koffarnus, Jarmolowicz, Mueller, & Bickel, 2013) – manipulations that can effectively influence this decision-making process are widely-sought. As a consequence, there has been considerable recent excitement about the potential role of episodic foresight in developing (early) interventions for impulsivity-related disorders, although this excitement has been hedged with ongoing discussion about the limits, generalizability, and transferability of any effects (Bickel et al., 2017; Bromberg, Lobatcheva, & Peters, 2017; Noël, Jaafari, & Bechara, 2017; Sze, Daniel, Kilanowski, Collins, & Epstein, 2015; Sze, Stein, Bickel, Paluch, & Epstein, 2017).

The specific mechanistic interpretation of how episodic foresight might impact intertemporal choice has varied widely, from considerations about the potential of imagining the future in engaging higher-level psychological construal (Y.-Y. Cheng et al., 2012), to the 'expansion' of the 'temporal window' of reinforcement information (Snider et al., 2016), greater identification or concern for one's 'future self' (O'Connell et al., 2015), the extension of 'temporal attention' (Kaplan, Reed, & Jarmolowicz, 2016), and the importance of framing effects (Jenkins & Hsu, 2017). In most cases, however, there is a common theoretical foundation suggesting that positive simulations of the future should lead to reduced discounting rates because the emotions engendered by these simulations can act as a 'motivational brake' on immediate preferences (Boyer, 2008). For instance, imagining a future payoff may provide a sufficient reinforcement to motivate goal pursuit at the expense of shorter-term alternatives. This is because imagining an emotional future event can trigger emotions in the here-and-now, "as if" the event were really occurring (Damasio, 2009; D. T. Gilbert & Wilson, 2007) – allowing people to anticipate the delayed value of their current patience. Indeed, there are a number of reasons to believe that the relationship between episodic foresight and intertemporal decision-making might ultimately depend on the emotional valence of the thoughts, including the catalogue of differences between the processes and consequences of positively and negatively valenced foresight (see Barsics et al., 2015; de Vito, Neroni, Gamboz, Della Sala, & Brandimonte, 2014).

The anticipation of negative, harsh, dangerous or uncertain future environments or scenarios might be expected to lead to a preference for immediate rewards inasmuch as one expects that the delayed reward is unlikely to materialise in such circumstances (Frankenhuis et al., 2016). In fact, one of the ultimate evolutionary explanations for delay discounting is that the future is uncertain, which might prevent one from being able to capitalize on delayed rewards (Bulley & Pepper, 2017). For example, in ecology, 'interruption risks' refer to the possibility that rewards might be lost before they can be obtained (Henly et al., 2008; Stephens, 2002), and an organism's death, of course, eliminates its ability to capitalise on delayed rewards (Daly & Wilson, 2005; Pepper & Nettle, 2013). Accordingly, anticipating future dangers, or one's death, may therefore engender 'impulsive' decision-making as a response to the likelihood that the future reward will not materialise, or that one will not be around to receive it (Bulley, Pepper, & Suddendorf, 2017; Santos & Rosati, 2015). In other words, there is good reason to suspect that decision-making profiles that have been labelled 'impulsive' are actually adaptive in certain circumstances, and this extends from behavioural ecology into various other domains in daily living, for instance in entrepreneurial endeavours where it is important to capitalize on fleeting opportunities (Gullo & Dawe, 2008). Thus, while impulsivity has been called “a predisposition toward rapid, unplanned reactions to internal or external stimuli without regard to the negative consequences of these reactions to the impulsive individual or to others” (Moeller, Barratt, Dougherty, Schmitz, & Swann, 2001), at least in some domains the ‘choice impulsivity’ pattern of behaviour might be generated not only by impulsivity *per se,* but by careful deliberation (see also Brezina, Tekin, & Topalli, 2009; Dickman, 1990).

Several lines of empirical evidence hint at the possibility that episodic foresight might affect delay discounting selectively depending on the content or valence of the thoughts. For instance, visualisation abilities (considered key to imagining future events in sufficient detail to generate the effect on delay discounting) have been found to correlate with *steeper* delay discounting (Parthasarathi, McConnell, Luery, & Kable, 2017), even though one study on adolescents found the vividness of episodic foresight imagery to correlate with reduced delay discounting elsewhere (Bromberg et al., 2015). In addition, a recent study found no association between delay discounting and *model-based control* (a formalisation thought to reflect the mechanism underpinning scene-construction and future event simulation) (Solway, Lohrenz, & Montague, 2017). Higher levels of explicit worry (negatively-valenced mental representations of future threat events) have been found to correlate with increased delay discounting (Worthy et al., 2014), as has imagining a stressful upcoming event (Lempert et al., 2012). There have also been two studies that directly examined the effect of negatively-valenced episodic foresight on intertemporal choice, both of which found that imagining negative future scenarios generally encouraged choices of smaller, sooner rewards (Liu et al., 2013; S. Zhang, Peng, Qin, Suo, & Feng, 2018). However, this effect has only been studied twice, in small samples. By contrast, research on the relationship between delay discounting and positively valenced episodic foresight has been studied more than twenty times with largely homogenous results.

#### 6.1.2. Risk-taking

In some regards, intertemporal choice and risk-taking can be grouped together under the construct of ‘impulsivity’, given that in both decision-making domains there exists the opportunity to prioritise immediate or potential delayed consequences. For instance, “risky” alcohol use involves trade-offs between immediate benefits (e.g. tension-reduction, pleasure) and potential large long-term negative consequences (e.g. health deterioration, costs to personal relationships). Other risk-taking behaviours including sexual promiscuity, violence and crime have a similar payoff structure, with high variance in potential outcomes – including trade-offs between immediate, highly rewarding outcomes and delayed, highly costly ones (Mishra, 2014; Mishra, Hing, & Lalumiere, 2015). Researchers are currently assessing the similarities and differences between the delay discounting and risk-taking constructs (Amir & Jordan, 2017; e.g. Luckman, Donkin, & Newell, 2017; Mishra & Lalumière, 2011). For example, risk-taking behaviour is often studied in the context of potential resulting punishments or harms (Lejuez, Aklin, Zvolensky, & Pedulla, 2003) whereas delay discounting is usually studied in the context of potential delayed rewards or benefits. There are a number of other key differences (Holt, Green, & Myerson, 2003), with the underlying personality variables that relate to each kind of decision process probably also being somewhat distinct – as evinced for example by the lack of significant correlations between common assessment tools (e.g. Xu, Korczykowski, Zhu, & Rao, 2013).

Whether or not episodic foresight affects impulsivity other than the kind expressed in strictly constrained intertemporal choice situations is of interest given the promise of such manipulations in modifying various real-world 'impulsive' behaviours such as overeating or alcohol abuse (e.g. O'Neill et al., 2015; Sze et al., 2017). While there have been some initial attempts to explore the potential influence of episodic foresight on probability discounting – which has analogues to risky behaviour (Kaplan, Reed, et al., 2016; Mok, 2017; Monroe, Ainsworth, Vohs, & Baumeister, 2017) – as well as some studies showing evidence that other mindset or framing manipulations can affect behavioural risk-taking (Keller & Gollwitzer, 2017), to our knowledge, as yet there has been no test of the potential effect of episodic foresight on behavioural risk-taking. Thus we sought to explore whether episodic foresight might affect behavioural risk-taking in a validated laboratory task – the balloon analogue risk task (BART), as it does in the context of laboratory intertemporal choice tasks. Given the conflicting evidence regarding the relationship between risk-taking and delay discounting, our analyses on this front were exploratory.

### 6.1.3. The present study

In the present study we therefore had two main aims. First, we aimed to replicate the effects of cuing positive and negative episodic foresight on delay discounting using a considerably larger sample than in prior studies. Second, we aimed to explore the effects of emotional episodic foresight on behavioural risk-taking for the first time. Participants completed modified laboratory measures of an intertemporal choice task (the 27-item Monetary Choice Questionnaire), and risk-taking (the BART). During both tasks, participants were prompted to imagine episodic future events or engage in neutral mental imagery. We hypothesized that cuing positively-valenced episodic foresight would result in lower delay discounting than a control imagery condition, whereas cuing negatively-valenced episodic foresight would result in higher delay discounting than a control imagery condition, in line with previous research. We were also interested in exploring the effect of positively- and negatively-valenced episodic foresight on risk-taking. All hypotheses were pre-registered through the Open Science Framework: https://osf.io/rfndu/.

## 6.2. Method

### 6.2.1. Participants

Participants were 301 undergraduate students who took part in the study for course credit. The study was approved by the University of Queensland School of Psychology Human Research Ethics Committee. Some participants were excluded from all analyses for inconsistent responding on the intertemporal choice questionnaire (consistency scores lower than 75%; n = 4), for discussion see Lemley et al. (2016) and Kaplan et al. (2016). Thus, the final sample comprised 297 participants (mean age = 19.72, SD = 4.03) of which 200 (67%) were female.

### 6.2.2. Design and procedure

Participants attended a single session that lasted approximately one hour. They were allocated randomly by the computer program (and blindly to the experimenter) to one of three groups: (1) positive episodic foresight, (2) negative episodic foresight, and (3) control (non-temporal) mental imagery. Participants first completed a visual analogue mood scale upon entering the lab, followed by a modified intertemporal choice task to assess delay discounting and the BART to assess risk-taking. These latter two assessments were counterbalanced. During both of these tasks, participants were presented with cues to engage in positive future, negative future, or neutral non-temporal mental imagery, depending on their experimental condition. Participants also completed the self-report Barratt Impulsiveness Scale-Brief (BIS-Brief) (Steinberg, Sharp, Stanford, & Tharp, 2013), Penn-State Worry Questionnaire (PSWQ) (T. J. Meyer, Miller, Metzger, & Borkovec, 1990), and Patient Health Questionnaire-9 depression inventory (PHQ-9) (Kroenke, Spitzer, & Williams, 2001), about which there were no explicit pre-registered hypotheses. At the end of the session, participants rated various aspects of their mental imagery during the tasks and provided demographic information. Details of all measures are as follows.

### 6.2.3. Measures and Manipulations

***6.2.3.1. Episodic foresight manipulation.*** The episodic foresight event cue words were derived from the Affective Norms for English Words (ANEW) list (Bradley & Lang, 1999). Ten words for each of the positive, negative and neutral valence conditions were selected (See Table 6.1). Short event descriptions were created with the selected words as the central component. Words were selected that enabled events to be created that were both plausible and simple, but also vividly imaginable (i.e. words were either action verbs or concrete nouns). The positive events were broadly those that participants would be likely to look forward to, while negative events concerned future threats (C. D. Blanchard et al., 2001). The neutral events were everyday activities without a temporal component. All of the event cues used in this experiment and ANEW valence ratings can be found in Table 6.1.

Participants were provided with a list of these 10 events (positive, negative or neutral depending on condition) and asked to select the 5 that were most relevant to them personally, in order to promote autobiographical episodic imagery during the task. The 5 events considered highest in personal relevance were then used as cues in the remainder of the experiment. Based on instructions for encouraging vivid imagination (D'Argembeau et al., 2008; Damasio et al., 2000) participants were instructed before the task that when they saw the imagination instruction, they should: "take a few moments to imagine yourself experiencing the event as vividly as possible. Produce detailed images of the events being imagined and concentrate on those images attentively. Include as much emotional and background detail as you can (e.g. where are you, what do you do, who is with you, what does it look and sound like, how does it make you feel?)". During the task, participants were instructed to imagine the events taking place at a certain amount of time in the future for the positive and negative future event cues (details in the 'intertemporal choice' section below). The neutral condition instructions made no mention of the temporality of the events; instead, participants were instructed to simply imagine this event, "as it would typically unfold, rather than remembering a particular occasion when you did this activity" (D'Argembeau et al., 2008). During the task, the imagination component was self-paced.

**Table 6.1.** Event cues used in the experiment and their respective ANEW valence mean and SD. The highlighted word is the keyword from the ANEW list around which the event was constructed.

| Positive (Mean, SD) | | Negative (Mean, SD) | | Neutral (Mean, SD) | |
|---|---|---|---|---|---|
| Dinner party | 7.16 (1.50) | Getting sick | 1.90 (1.14) | Using a pencil | 5.22 (0.68) |
| Visiting loved ones | 8.64 (0.71) | Traffic accident | 2.05 (1.19) | Leaning on a table | 5.22 (0.72) |
| Going on holiday | 7.55 (2.14) | Hurt by animal | 1.90 (1.26) | Using a bowl | 5.33 (1.33) |
| Birthday party | 7.84 (1.92) | Injury after falling | 2.49 (1.76) | Entering a building | 5.29 (1.15) |
| Seeing live music | 8.13 (1.09) | Getting an infection | 1.93 (1.87) | Opening a cabinet | 5.05 (0.31) |
| Success at university | 8.29 (0.93) | Assault by stranger | 2.03 (1.55) | Sitting on a chair | 5.08 (0.98) |
| Going to the beach | 8.03 (1.59) | Food poisoning | 1.98 (1.44) | Picking up some scissors | 5.05 (0.96) |
| Hanging out with friends | 7.18 (1.07) | Seeing an intruder | 2.77 (2.32) | Holding a hammer | 4.88 (1.16) |
| Winning an award | 8.38 (0.92) | Burn on hand | 2.73 (1.72) | Opening curtains | 4.83 (0.83) |
| Spending time in nature | 7.65 (1.37) | Venomous bite | 2.68 (1.81) | Folding up paper | 5.33 (1.37) |

***6.2.3.2. Intertemporal choice.*** The Monetary Choice Questionnaire (MCQ) (Kirby, 1999) presents participants with 27 choices between a smaller but sooner amount of money and a larger but later amount available after a certain delay (7 to 182 days). The task has been shown to have high test-retest reliability (Kirby, 2009). The MCQ can be used to calculate a general delay discounting parameter (‘k’) for each participant, such that greater k values represent steeper delay discounting (see ‘data analysis’, below). Episodic event cues were inserted into the code of the computerized task, to be presented before each decision in a manner that synchronized the temporal distance to both the possible future event and the delayed reward. For example, participants would be presented with a cue to imagine an event taking place in around 6 months before making a choice about a reward that was delayed by approximately that same amount of time. The event cues were presented on a screen preceding each of the 27 choice questions. Similarly to previous studies on the effect of foresight on intertemporal choice (e.g. H. Lin & Epstein, 2014), participants were instructed that they did not need to relate their decision to the event they imagined, but just to picture the event actually happening before making their choice. The event cues were tailored such that the time of occurrence approximated the receipt of the delayed intertemporal choice option. Figure 6.1 (top) shows the trial order and choice format for the MCQ. Table 6.2 shows a full list of the MCQ items and the groupings of the questions for the sake of the foresight manipulations.

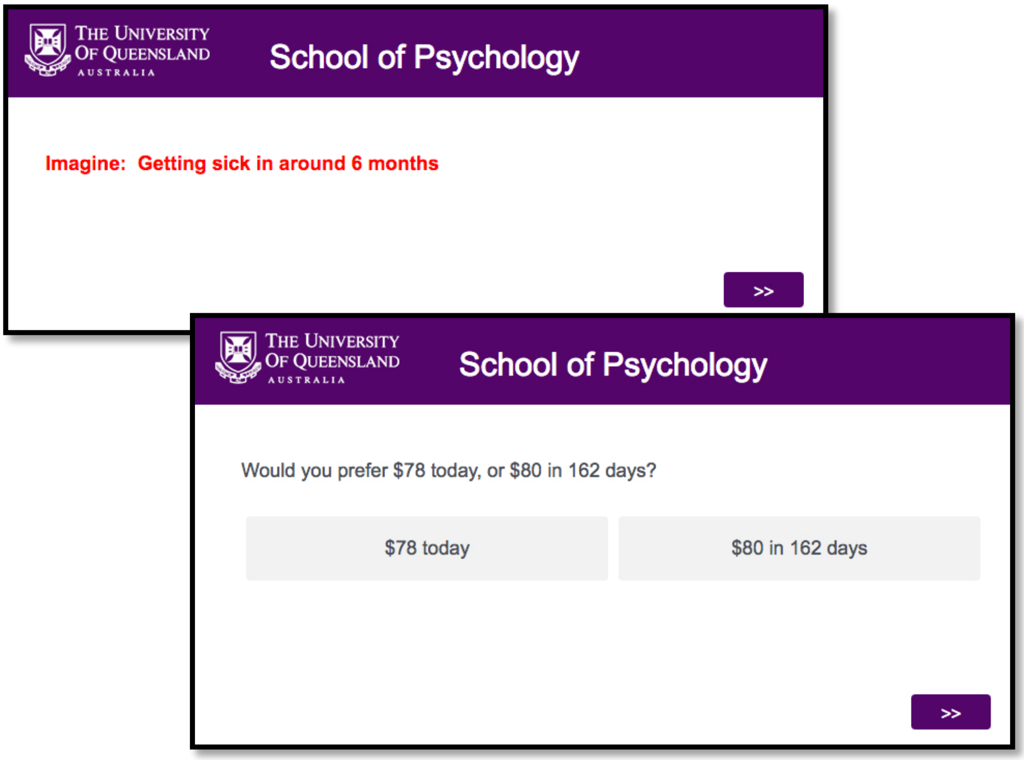
**Table 6.2.** Summary of the 27 MCQ questions, sorted by 'delay' (long to short). The shading of the delay column represents the groupings used in the episodic foresight task to produce event cues with delays approximating those of the choice questions. The first column presents the order of choice presentations. Each question is assigned a rank based on its k-index. The final column presents the magnitude grouping of the monetary amount offered in the corresponding choice (S = small, M = medium, L = large). Table based on Lemley et al, (2016) and Kirby (1999).

| | Monetary choice options | | | | | | |
|---|---|---|---|---|---|---|---|
| Order | Today | | Delayed | Delay | k-index | Rank | Magnitude |
| 13 | $34 | or | $35 | 186 | 0.00016 | 1 | S |
| 20 | $28 | or | $30 | 179 | 0.0004 | 2 | S |
| 9 | $78 | or | $80 | 162 | 0.00016 | 1 | L |
| 6 | $47 | or | $50 | 160 | 0.0004 | 2 | M |
| 17 | $80 | or | $85 | 157 | 0.0004 | 2 | L |
| 26 | $22 | or | $25 | 136 | 0.001 | 3 | S |
| 12 | $67 | or | $75 | 119 | 0.001 | 3 | L |
| 1 | $54 | or | $55 | 117 | 0.00016 | 1 | M |
| 24 | $54 | or | $60 | 111 | 0.001 | 3 | M |
| 15 | $69 | or | $85 | 91 | 0.0025 | 4 | L |
| 16 | $49 | or | $60 | 89 | 0.0025 | 4 | M |
| 22 | $25 | or | $30 | 80 | 0.0025 | 4 | S |
| 10 | $40 | or | $55 | 62 | 0.006 | 5 | M |
| 2 | $55 | or | $75 | 61 | 0.006 | 5 | L |
| 3 | $19 | or | $25 | 53 | 0.006 | 5 | S |
| 21 | $34 | or | $50 | 30 | 0.016 | 6 | M |
| 25 | $54 | or | $80 | 30 | 0.016 | 6 | L |
| 18 | $24 | or | $35 | 29 | 0.016 | 6 | S |
| 14 | $27 | or | $50 | 21 | 0.041 | 7 | M |
| 23 | $41 | or | $75 | 20 | 0.041 | 7 | L |
| 5 | $14 | or | $25 | 19 | 0.041 | 7 | S |
| 19 | $33 | or | $80 | 14 | 0.1 | 8 | L |
| 8 | $25 | or | $60 | 14 | 0.1 | 8 | M |
| 7 | $15 | or | $35 | 13 | 0.1 | 8 | S |
| 11 | $11 | or | $30 | 7 | 0.25 | 9 | S |
| 27 | $20 | or | $55 | 7 | 0.25 | 9 | M |
| 4 | $31 | or | $85 | 7 | 0.25 | 9 | L |

***6.2.3.3. Risk Taking.*** Risk taking was measured with a computerised version of the Balloon Analogue Risk Task (BART), (Lejuez et al., 2002) which was presented using E-Prime (Pleskac & Wershbale, 2014). Scores on the BART have been shown to predict risk-taking behaviours in a range of domains including unsafe driving, unprotected sex, gambling, stealing and substance use (Aklin, Lejuez, Zvolensky, Kahler, & Gwadz, 2005; Lejuez et al., 2002, 2003; Wallsten, Pleskac, & Lejuez, 2005), and the measure has been shown to have adequate test-retest reliability (White, Lejuez, & de Wit, 2008).

In each trial of the task, participants were presented with an image of a balloon, which they could 'inflate' by pressing the "F" key. Each button press slightly inflated the balloon and earned the participant 10 points. These points would accumulate during the trial but would all be lost if the balloon 'popped'. At any time during a given trial, the participant could choose to stop inflating the balloon before it popped, and opt instead to retrieve the money thus far collected on that trial by pressing the "J" key, moving it to a permanent 'bank'. The BART was programmed such that the optimal average number of pumps was 64 (for more details see Pleskac and Wershbale, 2014, p146). The 'total points' accumulated thus far in the permanent bank was displayed throughout the task on the right hand side of the screen alongside the points accumulated during the current trial. Event cues were presented on a separate screen preceding each balloon (before the fixation cross). Because the BART lacks an explicit temporal component, the event cues were entered with the same temporal specifications as the intertemporal choice questionnaire, but in an arbitrary order. On the event cue screen participants were instructed to 'press space to continue', which would take them to the next trial of the task. Before the experimental trials began, participants were given a single practice trial where they were not cued to imagine anything. Overall, participants completed 30 trials of the BART (30 balloons), though participants were not told in advance how many trials they would complete. Furthermore, each trial was self-paced (there was no time limit). For further details on the specifics of the BART program, see Pleskac and Wershbale, (2014). Figure 6.1 (bottom) shows the trial order and choice format for the BART.

(A)




(B)

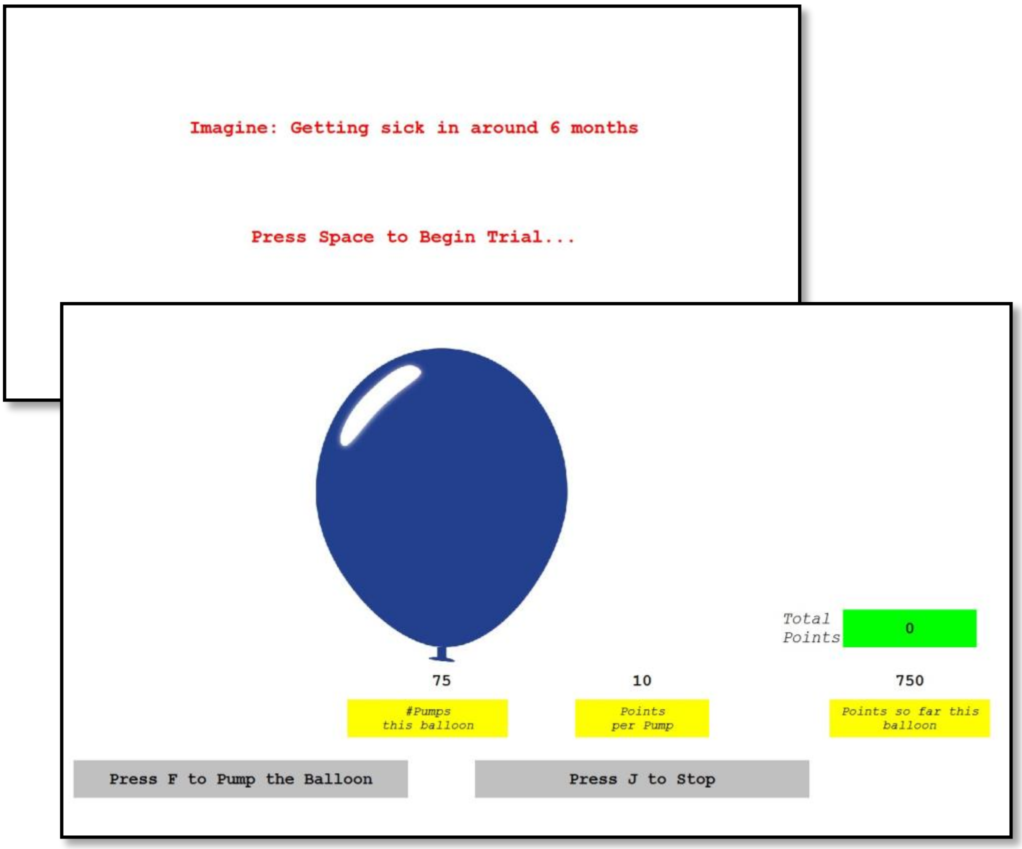



*Figure 6.1.* **(A):** Trial order in the MCQ – Intertemporal choice task question with preceding episodic foresight event cue instructions. **(B)**: Trial order in the BART – Participants were presented with a future event before moving to each subsequent balloon.

***6.2.3.4. Current Affect.*** Participants completed a visual-analogue mood scale (a slider ranging continuously from sad to happy) upon entering the lab such that higher scores were indicative of more positive affect. This measure was included to control for any possible effect of participants' baseline affective state on the measures of interest because there is some evidence for general mood effects on delay discounting (e.g. Hirsh et al., 2010).

***6.2.3.5. Event cue ratings.*** At the end of each session, participants rated the vividness, emotionality and personal relevance of their imagination of each event cue on scale from 1 (not at all) to 7 (very).

***6.2.3.6. Other measures.*** General levels of worry were assessed with the Penn-State Worry Questionnaire (PSWQ), a 16-item self-report questionnaire that measures the intensity of worry (T. J. Meyer et al., 1990). Severity of depression was assessed with the PHQ-9 depression inventory, a 9-item self-report questionnaire of depressive symptom frequency (Kroenke et al., 2001). Trait impulsivity was measured with the Barratt Impulsiveness Scale-Brief (Steinberg et al., 2013), an 8-item version of the longer BIS-11 (Barratt, 1959; Patton, Stanford, & Barratt, 1995).

**6.2.4. Data analysis**

Hypotheses, measures, and our analytical plan were pre-registered with the Open Science Framework: https://osf.io/rfndu/. All statistical analyses were performed in R studio (R Core Team, 2008), including the following packages: apaTables (Stanley, 2017), dplyr (Wickham, 2016), ggplot2 (Wickham, 2009), lemon (Edwards, 2017), ggsignif (Ahlmann-Eltze, 2017), psych (Revelle, 2015), reshape2 (Wickham, 2007), and Rmisc (Hope, 2013). The R script used for all data processing and analyses is available as an electronic supplement to this paper, as is the dataset and an information sheet about the included variables.

***6.2.4.1. Monetary Choice Questionnaire.*** A publicly available spreadsheet from Kaplan et al. (2014) was used to derive a temporal discounting ('k') value for each participant from the MCQ response data (Kaplan, Amlung, et al., 2016). The K value is a free parameter of a modelled hyperbolic discounting equation. A greater k value is indicative of steeper temporal discounting, (for individuals with a higher k value, rewards more quickly lose their subjective value with additional delays), and this acted as the primary outcome measure for the task. The data were normalized by a log-transformation of the raw values in accordance with our pre-registered plan and recommendations by Kirby & Maraković (1996). The MCQ has 27 questions, each with a different 'k-index' used to calculate the indifference point (and thus overall k value) for each participant. These question-level discounting-rate parameters (k-index) range from 0.00016 to 0.25 and include rewards of three magnitudes: 'small', 'medium', and 'large'. Table 6.2 contains a summary of all the intertemporal choice questions, including information about their respective k-indices and their order of presentation. We chose to analyse the MCQ data overall rather than for each magnitude separately as is sometimes done because we had no a-priori hypotheses about the effects of episodic foresight on discounting as a function of magnitude. Note that removing from analysis the participants who always chose the larger, later reward or always chose the smaller, sooner reward made no difference to the analyses below, and thus results are reported without excluding these participants.

***6.2.4.2. Balloon-Analogue Risk Task (BART).*** Scores were calculated as the average number of pumps per trial on trials in which the balloon did not burst (Lejuez et al., 2002), as is standard practice. The resulting adjusted pump scores approximated a normal distribution and were used in all analyses.

***6.2.4.3. Inferential statistics.*** We created two linear regression models to test the effect of episodic foresight on both the MCQ and the BART. This marked a change to the pre-registered analytical plan (which was to use ANCOVAs) for the sake of interpretability, but note that both analyses produce the same pattern of results. We controlled for age, sex, and baseline affect in each model and included experimental condition as a dummy-coded categorical predictor. Some additional exploratory analyses can be found in the supplementary document, pertaining to the relationship between the MCQ and the BART, and the relationship between the MCQ and self-reported impulsivity. Controlling for BIS, PSWQ and PHQ-9 scores in the main models assessing both MCQ and BART as outcome measures did not affect the pattern of findings.

## 6.3. Results

### 6.3.1. Descriptive statistics

Table 6.3 presents descriptive statistics for the main study variables.

### 6.3.2. Event cue ratings

Participants rated that they felt significantly more negative when imagining the events in the negative condition (M = 2.37, SD = 0.70) than the neutral condition (M = 4.48, SD = 0.58), $t = 22.79$ $p < 0.001$, and significantly more positive when imagining the events in the positive condition (M = 5.88, SD = 0.67) than the neutral condition (M = 4.48, SD = 0.58), $t = 15.15$, $p < 0.001$. Participants rated the event cue imagery as significantly more personally relevant in the positive (M = 5.62, SD = 0.73) than the neutral condition

(M = 5.10, SD = 1.16), *t* = 3.820, *p* < 0.001, and significantly less personally relevant in the negative condition (M = 4.7, SD = 0.95) than the neutral condition (M = 5.10, SD = 1.16), *t* = -3.32, *p* < 0.01. Controlling for this difference in personal relevance in latter analyses did not affect results. There were no differences in participants' ratings of the vividness of their imagery between the three experimental conditions. Figure 6.2 (middle row) presents the valence, vividness, and personal relevance ratings separately for each experimental condition.

Correlations between the event cue ratings were explored separately for each experimental condition, and are presented in Figure 6.2 (top row). Despite there being no average differences between conditions in the vividness of imagination, this variable was differentially correlated with valence in each condition in the expected direction. This correlation was of large magnitude in the positive condition, r = .62, p < 0.001, and negative condition, r = -.54, p < 0.001, and of moderate magnitude in the neutral condition, r = .33, p < 0.001 (see Cohen, 1988). Figure 6.2 (bottom row) presents the relationships between the vividness and valence of the event cue ratings separately for each experimental condition. There was a similarly large positive relationship between the personal relevance of the events and the vividness with which they were imagined (0.55 – 0.67, all p < 0.001). Table 6.4 presents descriptive statistics for the event cue ratings separately for each condition.

**Table 6.3.** Descriptive statistics for study variables overall (n=297), and by experimental condition. VAS = Visual Analogue Scale; MCQ proportion (LL) = proportion of larger, later rewards chosen in the Monetary Choice Questionnaire; PSWQ = Penn-state worry questionnaire; PHQ-9 = Patient health questionnaire 9; BIS-Brief = Barratt Impulsiveness Scale-Brief.

| | **Overall (N = 297)** | | **Neutral (N = 101)** | | **Positive (N = 99)** | | **Negative (N = 97)** | |
|---|---|---|---|---|---|---|---|---|
| | Mean (SD) | Min – max | Mean (SD) | Min – max | Mean (SD) | Min – max | Mean (SD) | Min – max |
| Age | 19.72 (4.03) | 17.00 – 50.00 | 19.66 (4.03) | 17.00 – 50.00 | 19.56 (3.46) | 17.00 – 42.00 | 19.96 (4.56) | 17.00 – 45.00 |
| Affect (VAS) | 6.96 (1.62) | 1.00 – 10.00 | 6.98 (1.81) | 2.00 – 10.00 | 6.99 (1.38) | 3.00 – 10.00 | 6.90 (1.66) | 1.00 – 10.00 |
| MCQ k value | 0.01 (0.03) | 0.00 – 0.25 | 0.02 (0.02) | 0.00 – 0.10 | 0.01 (0.03) | 0.00 – 0.25 | 0.01 (0.03) | 0.00 – 0.20 |
| MCQ proportion (LL) | 0.50 (0.17) | 0.00 – 1.00 | 0.45 (0.14) | 0.15 – 1.00 | 0.55 (0.18) | 0.00 – 1.00 | 0.52 (0.16) | 0.11 – 0.96 |
| MCQ log k | -2.20 (0.60) | -3.80 – -0.60 | -1.99 (0.50) | -3.80 – -1.00 | -2.35 (0.64) | -3.80 – -0.60 | -2.28 (0.61) | -3.80 – -0.70 |
| BART Adjusted Pumps | 29.56 (11.98) | 4.17 – 64.21 | 30.70 (12.01) | 8.00 – 59.19 | 30.07 (11.39) | 7.79 – 64.21 | 27.87 (12.46) | 4.17 – 53.06 |
| Worry (PSWQ) | 55.42 (12.76) | 18.00 – 80.00 | 55.33 (12.85) | 21.00 – 78.00 | 54.51 (13.80) | 18.00 – 80.00 | 56.44 (11.54) | 33.00 – 79.00 |
| Depression (PHQ-9) | 7.43 (4.96) | 0.00 – 24.00 | 7.46 (4.95) | 0.00 – 24.00 | 7.08 (4.72) | 0.00 – 22.00 | 7.76 (5.22) | 0.00 – 24.00 |
| Impulsivity (BIS-Brief) | 16.38 (3.58) | 8.00 – 29.00 | 16.28 (3.47) | 10.00 – 25.00 | 16.74 (3.37) | 8.00 – 27.00 | 16.11 (3.89) | 8.00 – 29.00 |

**Table 6.4.** Descriptive statistics for event cue ratings in the neutral (n=101), positive (n=99) and negative (n=97) experimental conditions.

| | Mean | SD | Min | Max | Range |
|---|---|---|---|---|---|
| Neutral | | | | | |
| Vividness | 5.38 | 0.93 | 2.00 | 6.80 | 4.80 |
| Valence | 4.48 | 0.58 | 3.40 | 6.40 | 3.00 |
| Personal relevance | 5.10 | 1.16 | 1.00 | 7.00 | 6.00 |
| Positive | | | | | |
| Vividness | 5.38 | 0.85 | 3.00 | 7.00 | 4.00 |
| Valence | 5.88 | 0.67 | 4.00 | 7.00 | 3.00 |
| Personal relevance | 5.62 | 0.73 | 2.80 | 7.00 | 4.20 |
| Negative | | | | | |
| Vividness | 5.16 | 0.90 | 2.40 | 6.80 | 4.40 |
| Valence | 2.37 | 0.70 | 1.00 | 5.00 | 4.00 |
| Personal relevance | 4.65 | 0.95 | 2.00 | 6.40 | 4.40 |

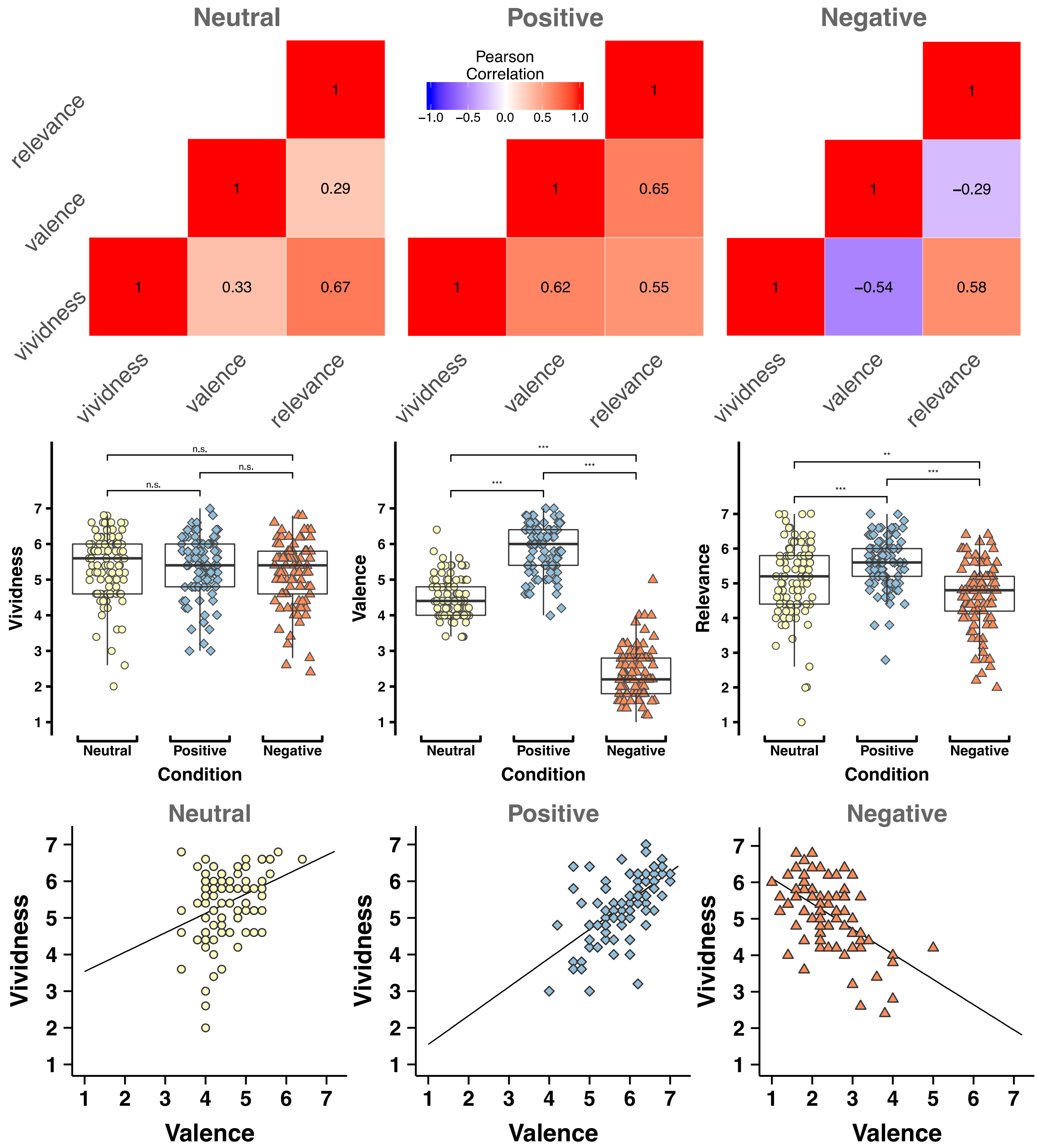



*Figure 6.2.* Post-task event cue ratings. ***Top***: Correlation matrix heat-maps of imagery ratings for each condition. Darker red means a larger positive correlation and darker blue means a larger negative correlation. Valence is scored from 1-7 such that low scores equate to negative valence and high scores equate to positive valence. All correlations: $p < 0.01$. ***Middle***: Event cue ratings of imagery vividness, valence, and personal relevance for each condition. Boxplot midline represents median. *** = Significant at $p < 0.001$. Horizontal jitter and some minor vertical jitter (<0.01 on Y-axis) have been added to aid in discrimination between data-points. ***Bottom***: Relationships between event cue ratings of imagery vividness and valence in each condition.

### 6.3.3. Effect of positive and negative episodic foresight on intertemporal choice and risk-taking

Experimental condition as predictor was positively associated with log-transformed MCQ k values as outcome after controlling for age, sex, and baseline affect. Participants in the positive foresight condition (M = -2.35 SD = 0.64) were on average more willing to wait for the larger, delayed rewards on the MCQ than participants in the neutral condition (M = -1.99, SD = 0.50), b = -0.36, [95% CI = -0.52, -0.19], $p < 0.001$, as were participants in the negative foresight condition, (M = -2.28, SD = 0.61), b = -0.29, [95% CI = -0.45, -0.13], $p < 0.001$. Table 6.5 presents the results of the regression with experimental condition as a categorical dummy-coded predictor with the neutral condition as the reference group. Analysing the data by the proportion of larger, later options chosen instead of k values produced the same results: on average, participants chose the larger later reward in 45% of the questions in the neutral condition, 55% of the questions in the positive condition, and 52% of the questions in the negative condition. For ease of interpretability, the proportion of larger, later options in each group is therefore presented in Figure 6.3 (top middle) alongside log-transformed MCQ k values.

Figure 6.3 (bottom row) presents the sample-level proportion of smaller, sooner rewards chosen (on the y-axis) for the varying k-indexes of the MCQ questions (on the x-axis). It indicates that the greatest magnitude of difference between the experimental conditions and the control condition pertained to those questions with ranks ranging from 4 to 6. Increasing rank is associated with larger discrepancies between present and delayed options and increasingly shorter delays (see table 6.2). Thus, Figure 6.3 indicates that the effect of episodic foresight on delay discounting is greatest for those questions with moderate discrepancies between immediate and delayed options and with moderate delays, such that all participants almost invariably (a) chose the delayed option when it was much larger than the immediate option and available after a short delay, and (b) chose the immediate option when there was little difference with the delayed option accompanied by a long delay.

Experimental condition was not associated with BART scores in a model adjusting for age, sex, and baseline affect, and the overall model was not statistically significant. There were no differences in the number of adjusted pumps in the BART on average between the experimental conditions, as illustrated in figure 6.3 (top right). Table 6.6 presents the results of the regression with experimental condition as a categorical dummy-coded predictor.

**Table 6.5.** Results of the multiple linear regression model assessing experimental condition as a predictor of log MCQ k values as the criterion, adjusting for age, sex, and baseline affect

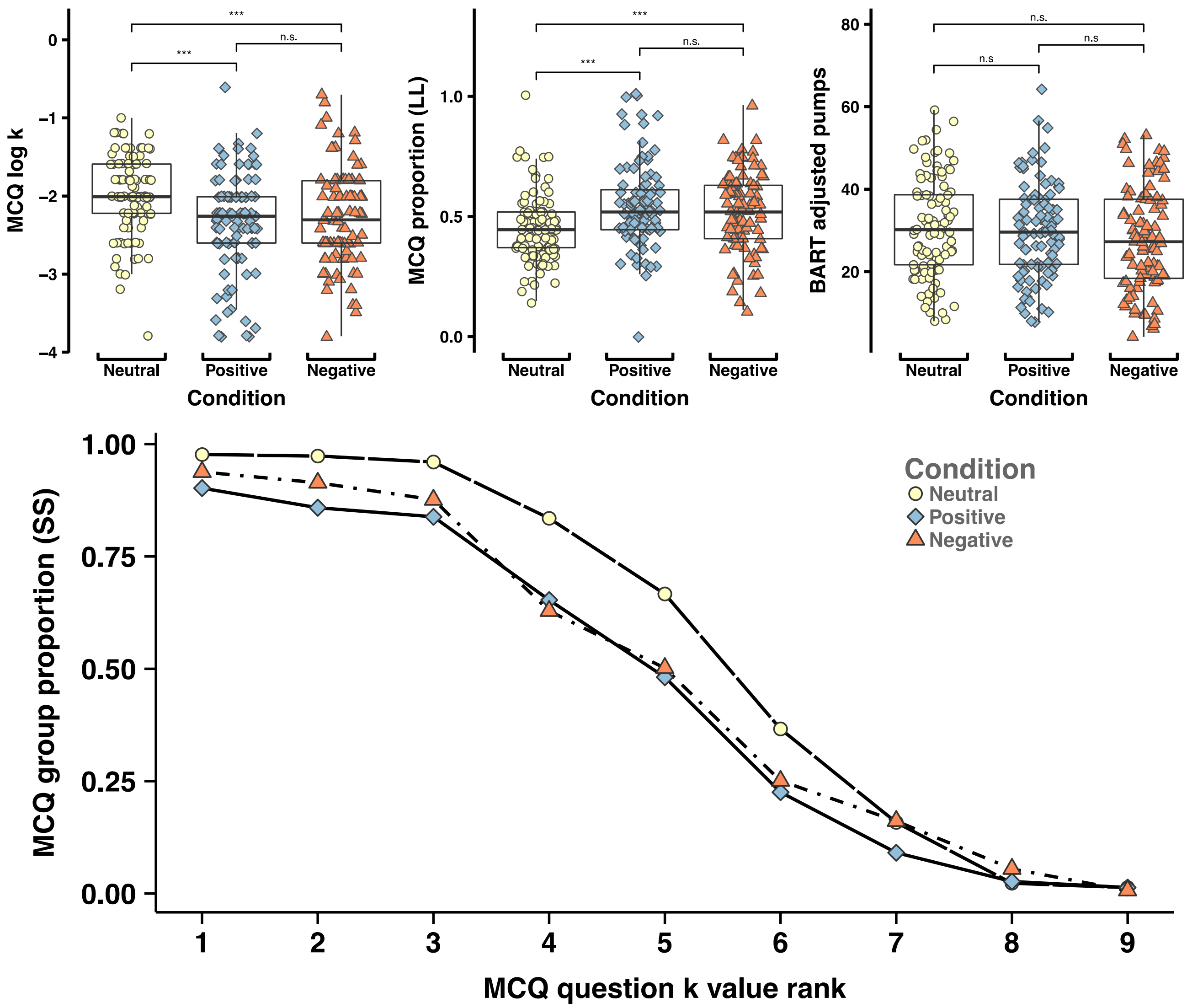
| Predictor | *b* | *b* 95% CI [LL, UL] | $sr^2$ | Fit |
|---|---|---|---|---|
| (Intercept) | -1.79** | [-2.25, -1.33] | | |
| Age | -0.00 | [-0.02, 0.02] | .00 | |
| Sex: male | 0.14 | [-0.00, 0.28] | .01 | |
| Current affect | -0.03 | [-0.07, 0.01] | .01 | |
| Condition: positive | -0.36** | [-0.52, -0.19] | .06 | |
| Condition: negative | -0.29** | [-0.45, -0.13] | .04 | |
| | | | | $R^2$ = .088**<br>95% CI [.02, .14] |

*Note.* * indicates p < .05; ** indicates p < .01. A significant *b*-weight indicates the semi-partial correlation is also significant. *b* represents unstandardized regression weights; $sr^2$ represents the semi-partial correlation squared. *LL* and *UL* indicate the lower and upper limits of the confidence intervals, respectively.

**Table 6.6.** Results of the multiple linear regression model assessing experimental condition as a predictor of BART adjusted pumps as the criterion, adjusting for age, sex, and baseline affect.

| Predictor | *b* | *b* 95% CI [LL, UL] | $sr^2$ | Fit |
|---|---|---|---|---|
| (Intercept) | 22.95** | [13.50, 32.40] | | |
| Age | 0.16 | [-0.18, 0.50] | .00 | |
| Sex: male | 1.24 | [-1.69, 4.16] | .00 | |
| Current affect | 0.60 | [-0.24, 1.45] | .01 | |
| Condition: positive | -0.62 | [-3.95, 2.71] | .00 | |
| Condition: negative | -2.84 | [-6.18, 0.51] | .01 | |
| | | | | $R^2$ = .022<br>95% CI [.00, .05] |

*Note.* * indicates p < .05; ** indicates p < .01. A significant *b*-weight indicates the semi-partial correlation is also significant. *b* represents unstandardized regression weights; $sr^2$ represents the semi-partial correlation squared. *LL* and *UL* indicate the lower and upper limits of the confidence intervals, respectively.




F*igure 6.3.* ***Top left***: MCQ log k values by experimental condition. ***Top middle:*** MCQ proportion (larger, later choices) by experimental condition***.*** ***Top right***: BART adjusted pump scores by experimental condition. In both plots, boxplot midline represents median. *** = Significant at $p < 0.001$. Horizontal jitter and some minor vertical jitter (<0.01 on Y-axis) have been added to aid in discrimination between data-points. ***Bottom****.* Proportion of group who chose the smaller, sooner reward rather than the later, larger reward at each k-value of the MCQ. For a question with a higher k-value rank, more participants are expected to choose the larger, later reward – for example, the following choice has a k-value rank of 9: "$31 now, or $85 in 7 days". At each k-value rank, the presented proportion includes the participants' responses to three questions from the questionnaire. The proportions are plotted separately for each experimental condition.

### 6.4. Discussion

In this study, we assessed whether and to what extent imagining positively- or negatively-valenced future events influences intertemporal choice and risk-taking. We tested the hypothesis that imagining positive future events during an intertemporal choice task shifts temporal preferences towards delayed rewards, and that imagining negative future events shifts preferences towards immediate rewards. Results were consistent with the first hypothesis, replicating the finding that imagining positive personally relevant future events reduces delay discounting. However, our results were inconsistent with the hypothesis that negative threat-related foresight encourages greater discounting, as has been observed in two previous studies (Liu et al., 2013; S. Zhang et al., 2018). Instead, we found that negative episodic foresight *reduced* delay discounting to a similar degree as positive episodic foresight. Furthermore, we observed no effect of imagining positive or negative future events on risk-taking in the balloon-analogue risk task. These findings will be discussed in turn below.

#### 6.4.1. The effect of foresight on intertemporal choice

In the present study, cuing positive and negative episodic future simulation increased the proportion of larger, later rewards chosen by 10% and 7% relative to control imagery, respectively. Although a number of studies have reported an effect of positively-valenced episodic foresight on delay discounting of a similar magnitude, this is the first study to report that negatively-valenced episodic foresight is associated with a similar reduction in delay discounting. We consider five possible interpretations of these effects below, after first comparing the current findings with two previous studies on the effect of negative episodic event cuing on delay discounting.

In both previous studies, episodic event tagging with negative future events (similar to the ones used in the current study) was associated with significantly increased delay discounting relative to a neutral condition (Liu et al., 2013; S. Zhang et al., 2018). It is unclear exactly why the current results diverge from these findings, but we note that the previous studies had substantially smaller sample sizes than the current one (N = 297, between-subjects neutral imagery vs. positive foresight vs. negative foresight). In Liu et al. (2013), study one (N = 32) employed a within-subjects design to compare control vs. positive foresight, and study two (N = 31) employed a within-subjects design to compare control vs. negative foresight. Zhang et al. (2018) employed a between-subjects design to compare neutral prospection (n = 34) vs. positive prospection (n = 34) vs. negative prospection (n = 32). Another difference in the design of the studies pertains to the control condition: Whereas Liu et al. (2013) used a passive control condition in which participants were not required to engage in prospection, Zhang et al. (2018) used an active control condition more akin to the present study in which participants were required to engage in neutral prospection. Otherwise, however, the experimental designs are highly similar (including in terms of the event cues, event ratings, laboratory choice task, and analytical approaches). It is worth noting, however, that the current study tested an Australian sample, while both previous studies examined Chinese participants. Thus, it is also possible that cultural differences may influence the way cued episodic foresight affects decision-making – though establishing this and potential underlying reasons would require dedicated studies.

With respect to the effect sizes of the studies, Liu et al. (2013) reported a medium effect size (Cohen's $d$ = .56) of negative foresight on the proportion of immediate-to-total choices relative to their control condition, and a medium-to-large effect size (Cohen's $d$ = .67) of positive foresight on the proportion of immediate-to-total choices compared to their control condition. Zhang et al. (2018) reported a large effect size (Cohen's $d$ = .89) comparing the proportion of immediate-to-total choices between negative foresight and neutral conditions, and a large effect size (Cohen's $d$ = -.76) comparing positive foresight and neutral conditions. The present study yields a medium effect size when comparing immediate-to-total choices between negative foresight and neutral conditions (Cohen's $d$ = .45) as well as when comparing positive foresight and neutral conditions (Cohen's $d$ = .63). Note again, however, that in the current study cued negative foresight reduced the proportion of immediate-to-total choices (reduced delay discounting), whereas in both previous studies cued negative foresight increased the proportion of immediate-to-total choices (increased delay discounting). We think the effect sizes reported by Zhang et al. (2018) are inflated because they used a between-subjects design with approximately 30 participants in each group. In contrast, Liu et al. (2013) used a within-subjects design with approximately 30 participants and the present study used a between-subjects design with approximately 100 participants in each group, and the effect sizes of these latter two studies are comparable.

Regarding the effects found in the current experiment, the first explanation is that the future event tagging manipulation might engender a generic change in 'future orientation'. For instance, Lempert & Phelps (2015) suggested that episodic future thinking "might serve to change time construal during choice". A central tenet of Construal Level

Theory (Trope & Liberman, 2010) is that future events are more 'psychologically distant' and are therefore 'construed' more abstractly than present ones. Imagining future events in detail therefore changes the construal level of 'future orientation' to a higher degree of concreteness (Y.-Y. Cheng et al., 2012). This in turn may have made the delayed option more attractive. This explanation appears to align with data from a recent study that showed actively manipulating construal levels – by encouraging future scenarios to be imagined with more concrete details – caused greater reductions in delay discounting (Kim, Schnall, & White, 2013).

However, if this interpretation rests on the greater 'future orientation' brought about by construal level changes, it may be challenged by a recent finding that remembering positive autobiographical events also reduces delay discounting (Lempert, Speer, Delgado, & Phelps, 2017) – though note that another recent study reported that there is no effect of episodic recollection on discounting (Daniel, Sawyer, Dong, Bickel, & Epstein, 2016). One way around this is to postulate that episodic memory affects discounting (if, indeed, this is borne out in further studies) because memories form the basis for future simulations – and that the function of memory is ultimately forward-facing (Bar, 2010; Klein et al., 2010; Lempert et al., 2017; Suddendorf & Henry, 2013). A problem with this conflation, however, is that despite the multiple convergences between memory and future simulation (Hassabis & Maguire, 2009; Schacter et al., 2012), they cannot be considered the same construct, with the same consequences (Klein, 2015; Suddendorf, 2010).

Nonetheless, given the possibility that episodic recall also results in reduced discounting, and the present results indicate that the emotional valence of episodic foresight does not have a differential effect on discounting, the second potential explanation of the current data pertains to the psychological effects of deliberative thinking *in general terms*. For instance, Bar (2010) in a response to Peters & Büchel (2010) notes that the effect might be "merely [because of] the fact that episodic information elicits richer associations and imagery, and it is this increased detail that improves valuation".

Dual process models of cognition have long emphasized the role of a slow, deliberative mode of thinking in decision-making (Kahneman, 2011), with the emphasis on how this mode can overrule more impulsive behaviour (for discussion and criticism see Koffarnus et al., 2013; Melnikoff & Bargh, 2018). Both of the above explanations about general deliberative thinking and general future orientation have received some support from studies suggesting that the effect of imagining the future on discounting appears to be relatively unrelated to some aspects of its content (e.g. imagining familiar vs. unfamiliar scenarios, Sasse, Peters, Büchel, & Brassen, 2015). However, this is contentious because other evidence suggests that the content does indeed matter (Daniel et al., 2016; Dassen et al., 2016), for instance with regards to its relevance to the respective decision or to one's personal goals (O'Donnell, Oluyomi Daniel, & Epstein, 2017). All three of the aforementioned studies were conducted with small sample sizes. However, if the findings reflect true effects, then it may be that there is a difference between the types of content assessed inasmuch as these differ in terms of the amount of deliberation they entail (e.g., personal goals and decision relevance may entail more deliberation than familiarity). Alternatively, as Schacter et al. (2017) argued: "The observation that the impact of episodic future thinking is contingent on the content of the imagined event indicates that it does not merely reflect a generic change in future orientation."

Third, the possible effect of the content of future simulations may be due to its preparatory and motivational aspects (Benoit, Berkers, & Paulus, 2018; Boyer, 2008; Bulley, Henry, et al., 2016). For example, Stein et al. (2017) have suggested that: "One interpretation of these findings is that [episodic foresight] broadens the temporal window over which individuals integrate the value of reinforcement, thus facilitating consideration of a behaviour's negative, long-term outcomes (e.g., lung cancer from smoking)." This is in line with perspectives on episodic foresight that emphasize its ultimate goal-related functions (e.g. Cole & Berntsen, 2015; D'Argembeau, 2016), insofar as people's personal goals often pertain to long-term outcomes for which reinforcement information is necessarily delayed.

In the current experiment, it is possible that foreseeing a future threat event engaged preparatory motivation (Miloyan, Pachana, et al., 2014; Miloyan & Suddendorf, 2015). For instance, planning for a future hardship might encourage people to choose a larger later reward in order to have the appropriate resources available when needed to manage the future circumstance effectively. In this context, it may be informative to assess the controllability of imagined future events: if a future threat is perceived to be more controllable, then preparatory behaviour (choosing the larger, later reward) may be more likely, whereas if the future threat is perceived to be outside of one's control, perhaps this would encourage a preference for smaller sooner rewards, given that the preparatory or motivational rationale for waiting for the larger reward is thereby undercut (Pepper & Nettle, 2014, 2017).

A fourth possibility is that episodic event tagging during the task 'primes' people to think about the future, which leads to reduced discounting through an enhancement of choices in line with this prime. This is consistent with one study that showed scrambled-sentence task priming of ‘future’ concepts reduced desires to engage in hedonic activities that have long term costs like excessive drinking (Y.-Y. Cheng et al., 2012). However, there is evidence that the ability to create a coherent vivid mental scene is related to the strength of the episodic tagging effect (Peters & Büchel, 2010). Furthermore, older adults and people with amnesia, who show marked deficits in generating episodic detail do not appear to receive the effect of episodic event tagging during intertemporal choice (Palombo, Keane, & Verfaellie, 2016; Rosenbaum et al., 2015; Sasse, Peters, & Brassen, 2017) – though see Kwan et al. (2015) for some conflicting results in the context of hippocampal amnesia. Importantly, however, priming studies are being called into question due to repeated failures to replicate even well-known priming effects (similar to the proposed one at hand) such as social and goal priming (e.g. C. R. Harris, Coburn, Rohrer, & Pashler, 2013; O’Donnell et al., 2018).

A fifth possible explanation is that the apparent effects of episodic foresight on delay discounting are due to demand characteristics. In a recent study, Rung and Madden (2018) provided participants with vignettes of interactions between experimenters and subjects regarding a study of the association between episodic foresight and delay discounting. They found that most participants could guess the purpose of the study. This suggests that demand characteristics in such study designs may explain the apparent effect of episodic foresight on delay discounting. Note, however, that another recent study found that the results of the episodic foresight manipulation on delay discounting (and cigarette demand) remained significant after controlling for measures of demand characteristics such as expectancies about the experimental hypotheses (J. S. Stein et al., 2017). We recommend that future studies control for demand characteristics by assessing whether participants are aware of the study hypotheses as a covariate. It will also be important to determine what potential demand effects are at play in the context of specific hypotheses about the role of episodic future event cuing such as the role of emotion studied here.

Overall, it remains a challenge for future research to determine which of the above explanations is correct and in what circumstances they apply. One significant hurdle to overcome will be in accounting for (often subtle) differences between both the cuing manipulations - which vary in terms of key features such as whether or not participants are explicitly told that the imagination component of the task need not relate to the decision component – as well as the delay discounting tasks, which vary on dimensions including the magnitude of the rewards, time delays, and choice framing.

### 6.4.2. No effect of future thinking on risk-taking

The current results revealed that the average number of balloon pumps in the BART was not significantly different between the three conditions. Thus, there was no evidence that imagining the future, with any emotional valence, affects risk-taking in this laboratory paradigm relative to neutral imagery. One explanation of these data is that episodic foresight does not necessarily have a blanket influence on all choice domains under the 'impulsivity' umbrella – i.e. those without an explicit long-term outcome structure such as the BART.

While this is the first study to our knowledge to explore the effect of episodic cuing on behavioural risk taking in the BART, three previous studies have examined the effect of cued episodic foresight on risk preferences in the context of probability discounting and risky investing. Probability discounting tasks assess the extent to which participants discount the subjective value of probabilistic outcomes (rather than delayed ones). Kaplan et al. (2016) assessed probability discounting of both gains and losses, and found that exposing people to age-progressed images of their own face (perhaps somewhat analogous to the episodic future event cuing) reduced this discounting. However, this study was conducted with only five participants in experiment one, and six participants in experiment two, presumably due to the difficulty of creating the age-progressed images of participants, and thus any inferences on the basis of this data are premature – as the authors acknowledge when they call the paper a 'proof of concept'.

In a study by Monroe et al (2017), participants who wrote a letter to their 'future self' favoured significantly less risky investments than participants who wrote a letter about their current self, suggesting that thinking about the future may heighten aversion to potential loss when considering long-term investments. In Mok et al. (2017), episodic future event cuing (similar to the manipulation used in the present study) did not affect probability discounting, but did reduce delay discounting. These results are consistent with the current null effects of future episodic event cuing on behavioural risk-taking, as well as the interpretation that cueing episodic future events is not sufficient to influence all tasks that assess aspects of impulsivity. As mentioned earlier, this is probably due to the fact that impulsivity is a highly multidimensional construct. Indeed, it is unclear how the BART as an index relates precisely to other risk elicitation methods such as probability discounting (for review see Charness, Gneezy, & Imas, 2013).

It will be important to consider the potentially selective (domain specific) effects of episodic foresight in the development of cognitive and behavioural strategies that have future imagination at their core (Snider et al., 2016). Clinical translation of recent findings about the potentially causal role of foresight in decision-making will require appropriate caution given concerns regarding the potential for demand characteristics to explain these effects (Rung & Madden, 2018a). The present findings are potentially in line with the idea that demand characteristics contributed to the effect of cued episodic foresight on decision-making, given that the manipulation only affected *choice impulsivity* domains with an *explicit* intertemporal trade-off, and not risk-taking – which lacks an explicit time component; and given that there was no temporal component in the neutral condition event cues for either task. Note, however, that there are other plausible reasons why we did not observe an effect of positive and negative foresight on risk-taking (e.g. due to the influence of unmeasured moderating variables such as the perceived 'controllability' of the simulated events), and identifying these reasons should be an avenue for future research. For instance, future research could directly modify the timing of outcomes in a risk-taking task with episodic future event cuing to explore whether decisions pertaining to short-term consequences (such as in the BART) differ in their susceptibility to cuing relative to long term consequences (such as in the Monroe et al. (2017) investment study that found reduced risk-taking after cuing future-oriented cognition).

### 6.4.3. Limitations

There are a number of limitations to the current study that should be acknowledged. Firstly, there may have been an unintended effect of repeated simulation, for instance on the estimated likelihood of the events happening (Szpunar & Schacter, 2013). Relatedly, it is also possible that the act of repeated simulation caused participants to reduce their engagement in vivid imagination or to habituate to the emotional content therein. However we did counterbalance the BART and the intertemporal choice task, so any between-task consequences of this reduction in episodic simulation detail with time should not have influenced the key contrasts of interest. Secondly, ratings of episodic simulations in response to the event cues were measured after the tasks were completed, meaning they were reliant on participant's recollection of their previous simulations, and may have therefore been more erroneous than immediate ratings. In the same vein, other than verbal self-report there is no way to verify that participants are actually following the task instructions and engaging in episodic foresight when cued due to the subjective nature of the manipulation. Thirdly, demand characteristics may have played a role in the findings, as discussed above (Rung & Madden, 2018a). It is also relevant to note that the intertemporal choices were hypothetical. Although there is generally good correspondence between real and hypothetical rewards in decision-making tasks (Lagorio & Madden, 2005; Madden, Begotka, Raiff, & Kastern, 2003), there are also important differences that should be considered (Camerer & Mobbs, 2017; Xu et al., 2016). Incidentally, the use of hypothetical rewards also limits the relevance of comparisons with non-human animals, who almost always actually experience the delays and receive the rewards when performing intertemporal choice tasks (Palombo et al., 2015; Redshaw & Bulley, 2018). Future studies of the role of foresight in tasks such as the 'experiential discounting task', in which delays are actually experienced, will be informative (Reynolds & Schiffbauer, 2004). Similarly, future research should examine how people might naturalistically employ foresight in their everyday decision-making, for instance by using a longitudinal thought-sampling protocol with specific probes to target which strategies people use to make intertemporal trade-offs. Finally, the relatively homogenous nature of our sample restricts the generalizability of our findings (Henrich, Heine, & Norenzayan, 2010), as well as that of the majority of previous studies of the effect of foresight on delay discounting. This is particularly important in addressing any evolutionary claims about the potential adaptive function of episodic foresight in modulating decision-making.

### 6.5. Conclusion

To make decisions with outcomes that play out over time, humans can use information derived from mental simulations of possible futures. The present study adds to a body of research demonstrating plasticity in intertemporal decision-making in response to such mental simulations of the future. We found that cuing the imagination of positive and negative future events, regardless of the affective content of these events, reduced delay discounting relative to control imagery. However, cued positive and negative episodic foresight had no effect on risk-taking in a standard laboratory task. These results thereby replicate previous findings suggesting positive foresight can reduce discounting, but are inconsistent with the hypothesis that anticipating a generally threatening future event would encourage a greater preference for immediate rewards, as reported in two previous studies. Finally, the present results suggest that the effect of foresight on 'impulsive' decision-making is selective, insofar as it operates on delay discounting but not risk-taking.

## Chapter Seven. The future-oriented functions of the imagination: From prediction to metaforesight

**Bulley, A.,** Redshaw, J., & Suddendorf, T. (In press). The future-oriented functions of the imagination: From prediction to metaforesight. *The Cambridge Handbook of the Imagination.* Cambridge University Press, Cambridge.

### Preface and details of contribution to authorship:

This chapter surveys some of the most critical functions of the prospective imagination, including but not limited to the ones outlined in the thesis thus far. In each case, it is argued that metacognition – our ability to think about our thinking – bolsters these capacities. The chapter introduces the term *metaforesight* to describe the processes involved in monitoring, controlling, and ultimately augmenting prospection. I conceived the idea jointly with co-authors Jonathan Redshaw and Thomas Suddendorf. I wrote the first draft of the paper. All authors provided critical revisions.

## Abstract

One of the fundamental roles of human imagination is to enable the representation of possible future events. Here, we survey some of the most critical abilities that this foresight supports: anticipating future emotions, setting and pursuing goals, preparing for threats, deliberately acquiring skills and knowledge, and intentionally shaping the future environment. Furthermore, we outline how metacognition bolsters human capacities even further by enabling people to reflect on and compensate for the natural limits of their foresight. For example, humans make contingency plans because they appreciate that their initial predictions may turn out to be wrong. We suggest that the processes involved in monitoring, controlling, and ultimately augmenting future-oriented imagination represent an important and understudied parallel of “metamemory” that should be called “metaforesight”.

## 7.1. Introduction

> Man alone is able to manipulate time into past and future, transpose objects or abstract ideas in a similar fashion, and make a kind of reality which is not present, or which exists only as potential in the real world. From this gift comes his social structure and traditions and even the tools with which he modifies his surroundings. They exist in the dark confines of the cranium before the instructed hand creates the reality.
>
> – LOREN EISELEY, 1970, p. 145.

Where does our imagination come from, and what is it for? Here we argue that one of the primary roles of the imagination as an evolved system is to facilitate the acquisition of future benefits and the avoidance of future harms. To support this claim, we survey some of the most critical abilities enabled by the future-oriented imagination: anticipating future emotions, setting and pursuing goals, preparing for threats, making flexible decisions, acquiring masterful skills, and building powerful tools.

The idea that the capacity to imagine the future has adaptive behavioural consequences has a long history. The ancient Greeks believed that Prometheus (literally translated as '*foresight*') stole fire from heaven and gave it to human beings – the lowly animal left unequipped for the battleground of nature when capacities like teeth, claws and thick hides were doled out (Suddendorf, 1994). The ability to harness fire is indeed a prime example of the future-oriented power of imagination. Controlled fires demand not only a stockpile of combustible materials, but also knowledge of techniques to start, maintain, and contain the flames. Mastery in this domain thus requires a suite of cognitive capacities that draw heavily on the imagination, such as deliberate practice and planning. But the benefits are numerous and profound: light, warmth, protection, and cooking – to name a few. Human control of fire therefore illustrates the more general principle that imagining the future can be decidedly useful. Despite whatever costs it may entail, foresight has been a driving force in the evolutionary success of our species (Suddendorf & Corballis, 1997).

### 7.2. Surveying the future-oriented functions of imagination

Among the first modern thinkers to identify the significant adaptive future-oriented benefits of the imagination were Cyberneticists of the 1940s and 1950s. In an oft-quoted passage, Craik (1943, pp. 59-61) noted:

> If the organism carries a 'small-scale model' of external reality and of its own possible actions within its head, it is able to try out various alternatives, conclude which is the best of them, react to future situations before they arise, utilise the knowledge of past events in dealing with the present and the future, and in every way to react in a much fuller, safe, and more competent manner to the emergencies which face it.

Many authors have built on this concept of future-oriented 'mental models', and the resulting intellectual tradition is too rich for a full discussion here (see Bulley, 2018, for a review). In short, many prominent theories suggest we should consider the imagination as a kind of *simulation* – often *predictive* – of interactions with the environment (Barsalou, 2009; Clark, 2015; Hesslow, 2012; Pezzulo, 2008; Schacter et al., 2008). Seen through this lens, the experiences that people have throughout their lives form the raw material for the predictions they make about the future (Hassabis & Maguire, 2009; Irish & Piguet, 2013; Klein, 2013b; Schacter et al., 2012; Suddendorf & Corballis, 1997; Szpunar, 2010). This does not mean, however, that people are inflexibly bound to anticipate only that which has come before. On the contrary, human imagination enables people to foresee situations they have never previously experienced by combining basic elements from memory into novel constellations. The scenarios people build in their imaginations transform and branch in real-time as different paths of future action are considered and compared in terms of their likelihood and desirability.

Humans often *deliberately* imagine the future, for instance when hatching a plan or pondering what goals to pursue. However, at times people seem just to daydream and inadvertently stumble upon future possibilities. Thus, some researchers have suggested a distinction between voluntary and involuntary mental time travel into the future (Finnbogadóttir & Berntsen, 2013), and others have suggested that people tend to move back and forth between these modes when their minds wander (e.g., Seli et al., 2018). The key point to recognize is that imagining the future is a decidedly common human activity, even to the extent that people cannot help but occupy themselves with it when they have nothing much else to focus on (Corballis, 2013). In this section, we consider why this tendency is so quintessentially human, by highlighting some of the powerful abilities that imagining the future enables. We then explore how even more powerful benefits are unlocked by our capacity to reflect on and critically appraise our simulations of the future – through what we call *metaforesight*.

### 7.2.1. Affective forecasting and goals

Imagining the future enables people to *evaluate* alternate possible paths forward, and to therefore choose which to pursue. A common way to evaluate outcomes is to anticipate how we would *feel* if they happened, and this has been called *affective forecasting* (D. T. Gilbert & Wilson, 2007). Simulating an interaction with the environment allows people to respond emotionally 'as-if' the event were really occurring (Damasio, 1994; Pezzulo, 2008). However, the relationship between emotion and foresight is complex. Aside from *anticipated* emotions (those predicted to occur in response to a future event), humans also have *anticipatory* emotions felt in the present about an upcoming event, such as excitement or dread (Berns et al., 2006; Loewenstein & Lerner, 2003). The very act of anticipation can be strongly emotive – as the German vernacular recognizes: "Vorfreude ist die schönste Freude" (anticipated joy is the greatest joy).

*Goals* are desired possible future states, which implies an emotional assessment of potential scenarios. However, a goal is more than an "affective forecast" or a basic evaluation of a possible situation – it is a *motivator* (Pezzulo & Rigoli, 2011). Once emotions have been forecasted, they can rally cognitive and behavioural resources towards or away from different possible future scenarios. Indeed, mental simulations of the future tend to cluster around personal objectives (D'Argembeau, 2016). People can even anticipate drive states and physiological needs they do not currently possess – an ability perhaps out of reach for other animals (Bischof-Köhler, 1985; Köhler, 1925; Suddendorf & Corballis, 2007). Humans alone build fires before they are cold and stuck in the dark.

### 7.2.2. Preparation for threats

This same ability to anticipate future emotions and organise current behaviour accordingly underlies flexible and advanced preparation for future dangers (Miloyan, Bulley, & Suddendorf, 2018; Miloyan, Bulley, et al., 2016). Of course, many different species exhibit a capacity for defence in the face of *immediate* danger. Indeed, some animals even have sophisticated responses to indicators of their own vulnerability (M.

Bateson, Brilot, & Nettle, 2011). For example, starlings spend more time glancing around when they are foraging further apart from their flock neighbours – and thus are more susceptible to attacks (Devereux, Whittingham, Fernández-Juricic, Vickery, & Krebs, 2006). But humans can prop open the window of time for defence still farther. With the imagination, anxiety can be evoked regardless of what is currently perceived. Humans were therefore motivated to craft spears that would only later pierce the heart of their predators (Bulley, Henry, & Suddendorf, 2017).

In addition to extending the preparatory window, it is the *flexibility* afforded by foresight that makes human defence so uniquely powerful. Consider the burrows that many animals create, into which they can scurry when they sense a nearby predator. Although burrows can be very complex, they are nevertheless built according to fixed rules and offer only a limited set of hiding places. Humans, however, can anticipate the failures of their hiding places and therefore place a trap at the entrance, cause a distraction, or create a hidden escape route, and rapidly adjust these strategies when they learn about new threats and possibilities. Consider, for instance, the ingenious ways in which human cities have subsisted during prolonged periods of siege warfare, by employing walls, tunnels, moats, traps and all sorts of sophisticated battle plans, distractions and deceit.

### 7.2.3. Flexible decision-making

It should be clear that imagining the future allows humans to fine-tune their behaviour to optimise long-term outcomes. Often, however, present-moment behaviour is pitted *in opposition* to future outcomes – for example when capitalising on some opportunity *now* cuts off paths to a possibly greater but *delayed* reward. Humans, like other animals, face a variety of ‘intertemporal’ trade-offs as a result (Loewenstein et al., 2003; Stevens & Stephens, 2008). To eat the fruit now, or wait for the added taste and nutrition afforded by it ripening?

The capacity to subordinate immediate pleasure to more long-term aims has long been emphasized as a strategy for personal success and as a powerful tool in the arsenal of human cognition (Ainslie, 1975; Baumeister & Tierney, 2011). Mischel’s seminal marshmallow tests with young children are prominent examples of early psychological work on the topic (Mischel et al., 1989). However, the question of how humans deal with such trade-offs has been studied since antiquity; for instance as Plato’s concept of *akrasia* (e.g., Rorty, 1980). Akratic behaviours are those in opposition to one’s own better judgement, with the word akrasia literally translating to “without strength” or “lacking command”. Akrasia is also core to many world religious traditions: one must wait patiently and act prudently in the now for the promise of reward in the afterlife. Thus, there is often a struggle between immediate gratifications and higher ideals or goals (which is in many cases to simply say imagined future payoffs).

Human adults' intertemporal trade-offs are studied in many ways, but perhaps most commonly with so-called *intertemporal choice tasks*. In such tasks, participants make choices between immediate and delayed rewards, such as between $25 today and $60 in 14 days (Kirby et al., 1999). The extent to which someone discounts future rewards can be calculated based on their answers to multiple intertemporal questions with different values and delays. Recent evidence suggests that imagining future events when making intertemporal choices can shift preferences towards future outcomes, reducing delay discounting. For example, in a study by Peters and Büchel (2010), participants chose between monetary rewards such as 20€ now, or 35€ in 45 days – while sometimes being cued to imagine an actual event they had planned around the same time as the delayed option. When they were cued in this way, participants more often said they would be willing to wait for the extra euros, and the more vividly they reported imagining the event, the stronger the shift in their preferences (for reviews see Bulley, Henry, et al., 2016; Schacter et al., 2017). This work dovetails with numerous theoretical perspectives on the role of the imagination in intertemporal preferences. Boyer (2008), for instance, suggested that one evolutionary function of imagining the future is to act as a motivational brake on shorter-term impulses such as the temptation to take advantage of another person for selfish gains.

It is important to note, however, that prudent reflection may not always encourage choices for delayed over immediate rewards. Sometimes it is most beneficial to pursue instantly available rewards. As the saying goes: a bird in the hand is worth two in the bush. In nature, and in human cultural systems, delaying gratification fundamentally relies on trust that the anticipated or promised outcome will manifest. There are thus many circumstances where it is smart to take the immediate but smaller reward, such as when the future outcome is particularly uncertain or remote (Fawcett et al., 2012; Stevens & Stephens, 2008). But when put to the extreme, too much patience can result in decision makers dying "of starvation waiting for the windfall" (Santos & Rosati, 2015, p. 337). The challenge is to know when to pursue immediate gratification and when to work towards longer-term pay-offs.

Many critical human systems (including, but not limited to banks) fundamentally rely on the capability to establish long-term trust in the name of collaboration. The same is true even of rudimentary trading relationships in which goods and services are exchanged after a delay. A growing body of evidence suggests that foresight can encourage prosocial behaviour, implicating future-oriented imagination in establishing and solidifying interpersonal trust (e.g., Gaesser & Schacter, 2014). Conversely, violations of trust undermine the reasons for delaying gratification (Mischel, 2014). Even young children are less willing to wait for a delayed reward if the experimenter has broken a promise (Kidd et al., 2013).

### 7.2.4. Deliberate practice

To build a sustained fire, craft and use a sturdy weapon, or play an instrument, one must attain mastery of a skill. Practicing is the way to achieve such mastery. It requires thinking about one's future self as alterable. Once an upgraded future self can be envisioned, say with improved abilities and knowledge, people can become motivated to pursue steps towards making this a reality (Davis, Cullen, & Suddendorf, 2015; Suddendorf et al., 2016). Through many hours of practice humans pursue a seemingly endless variety of skills. And while deliberate practice usually involves repetitions of physical actions, it is also the case that humans can improve their skills by merely *imagining* the relevant actions (e.g., Coffman, 1990).

Some of the earliest material evidence for deliberate practice in our lineage comes in the form of Acheulean handaxes and cleavers associated with *Homo erectus* (Suddendorf et al., 2016). The oldest surviving examples of the symmetrical handaxes – which potentially had many different uses including cutting meat from carcasses, digging for tubers, and woodworking – are over 1.76 million years old (Lepre et al. 2011). There are some archaeological sites where a bounty of bifacial handaxes lies discarded, for example at Olorgesailie in Kenya. This abundance of intricately crafted tools suggests that their makers were *practicing* the manufacturing skill. After all, if merely a handaxe was needed, they could have just picked up one of the ones lying around. Instead, new ones were made again and again, and their makers would have carried with them not just a tool, but the capacity to craft a new one whenever needed (Suddendorf et al., 2016). The tools themselves exhibit signs of effortful and detailed production, such as an aesthetic bi-directional symmetry that would have required mastery of the relevant knapping skills (Mithen, 1996; Shipton & Nielsen, 2015). The tools are complex and uniform enough that they must also have emerged through iterative social learning, and perhaps teaching (Legare & Nielsen, 2015; Whiten & Erdal, 2012).

Another hypothesis about the overabundance of Acheulean handaxes is that they represent a form of sexual signalling of desirable qualities such as the competence of the creator (Kohn & Mithen, 1999). However, this possibility is clearly complementary with the deliberate practice account. Even as a sexual signal, the creation of a bifacial handaxe requires deliberate practice of flint knapping. Consider the West Tofts handaxe, which has a shell embedded at its centre. The creator of this object appears to have selected the flint and knapped it so that the shell stayed in the middle — demonstrating not only competence but perhaps also a sense of beauty (Oakley, 1981)[4]

*Figure 7.1.* The West Tofts Handaxe. A shell of the Cretaceous bivalve mollusc Spondylus spinosus is embedded at the centre of the tool. *This image is copyrighted. Reproduced by permission of University of Cambridge Museum of Archaeology & Anthropology (accession number 1916.82).*

[4] It is also possible that the shell placement is a complete coincidence. The interpretation of handaxes in general, and especially with regards to what they tell us about ancient cognition, is contentious within archaeology (for example see Machin, 2008).

### 7.3. Compensating for anticipated limits: introducing "metaforesight"

Humans, perhaps uniquely, are capable of meta-representational insight into the relationship between their imagination and reality. In other words, people can evaluate how imagined scenarios link in with the external world, and thus assess whether what is imagined is likely to actually occur in the future, and whether it is biased, pessimistic, or hopeful and so forth. In the broad sense, meta-representation involves representing the relation between (i) a representation and (ii) what that representation is *about* (Pylyshyn, 1978). The development of such a capacity in childhood is widely considered as critical to the emergence of an understanding of *other people's* minds (e.g. Perner, 1991). In the domain of foresight, this form of metacognition has long been given a central role (Suddendorf, 1999). Once one appreciates that one's thoughts about the future are *just* representations, one is in a position to evaluate them, to modify them, to discount them, to discuss them, and to try to compensate for their shortcomings (Redshaw, 2014; Redshaw & Bulley, 2018). Indeed, this capacity may be crucial to children acquiring a mature sense of future time itself – as a series of possible chains of events of which only one will actually happen (see Hoerl & McCormack, 2018).

In this section, we will discuss a number of ways that metarepresentational foresight unlocks a new suite of adaptive benefits for future-oriented imagination in each of the domains surveyed above. Our primary argument is that metacognition enables people to evaluate the strengths and limitations of their own predictions and the future operation of other cognitive systems. These insights can then drive compensatory action in preparation for possible cognitive failures, such as contingency planning and the use of external reminders (Redshaw & Bulley, 2018; Risko & Gilbert, 2016). We propose that together these processes be called *metaforesight*. Given the established links between memory and foresight, this name offers a fitting parallel to *metamemory*. Metamemory processes are those that enable people to monitor and control their memory capacities, and this has long been a subject of intense research (Bjork, 1994; Dunlosky & Tauber, 2016; Flavell & Wellman, 1975; Nelson & Narens, 1990).

We have recently begun to examine how aspects of metaforesight develop in childhood, and whether certain fundamentals are shared with other animals. In one study, children and great apes were given the opportunity to catch a desirable target dropped into an inverted "Y" shaped tube. Two-year-old children and apes typically covered only a single exit from the tube, and thus missed the reward on approximately half of the trials. By age four, however, most children consistently covered both exits from the first trial onwards, ensuring they would always catch the reward (Redshaw & Suddendorf, 2016). One interpretation is that the older children understood that their prediction of the future target location *could be wrong*, and that therefore it was worth ‘covering both bases’ (Redshaw, Suddendorf, et al., 2018; Suddendorf, Crimston, & Redshaw, 2017).

In another recent study, we tested young children’s metacognitive compensation for their anticipated memory failures (Redshaw, Vandersee, Bulley, & Gilbert, 2018). Children aged 7 to 13 were given a computerized task which required them to remember to carry out future intentions after a delay – analogous to a prospective memory situation such as needing to remember to bring home a book from school (Brandimonte, Einstein, & McDaniel, 2014). We then gave participants the opportunity to *set themselves reminders* of the future intentions if they wished to do so. Children of all ages demonstrated appropriate knowledge about their potential memory failures – recognizing that it would be harder to perform the task when there were more intentions to remember. However, we found that only children from about 9 years onwards set themselves more reminders in conditions in which they anticipated their future memory performance would be worse.

This task therefore captures elements of both metamemory (monitoring of own memory limitations) as well as metaforesight (anticipating how memory might or might not fail in possible futures). Children’s age-related improvements on these specific tasks may be driven by more general developments in both *metacognitive insight* and *metacognitive control*. Metacognitive insight refers to beliefs about the capacities and limitations of our own minds (Nelson & Narens, 1990), and typically develops during the preschool years. Even 3.5-year-olds, for instance, seem to understand when they are uncertain about the location of a hidden object (Neldner, Collier-Baker, & Nielsen, 2015) or if they have previously learned an item from a memory list (Balcomb & Gerken, 2008). Metacognitive control, on the other hand, refers to the use of metacognitive insight to flexibly adopt behavioural strategies in varied situations, and typically develops during the primary school years. For example, although 6- and 7-year-olds know the difference between easy and hard items to learn for a memory test, only around age 9 do children dedicate proportionately more time to studying hard items than easy items (Dufresne & Kobasigawa, 1989). Such fundamentals of metaforesight may underlie a range of powerful abilities that we will now explore in more detail.

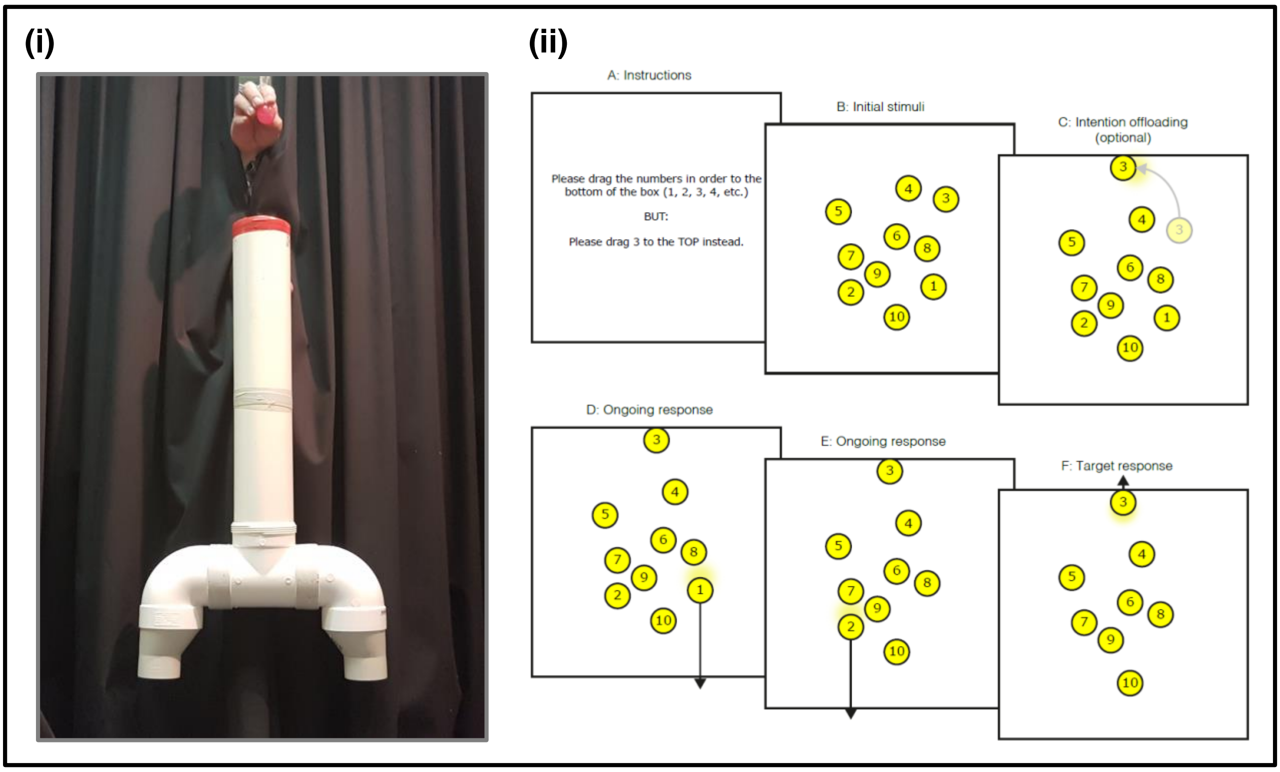



Figure 7.2. Recent studies into the fundamentals of metaforesight in development. (i) Catching the ball dropped into the tube is guaranteed only by covering both exits simultaneously – a rudiment of contingency planning. (ii) In a reminder-setting task, participants drag numbered circles in ascending order to the bottom of the box. They must also remember to carry out either one or three alternative actions for specific numbers (dragging them to a particular edge) (A-B). In some conditions, participants have the option of dragging the target circles to the relevant edge of the box at the beginning of the trial – a reminder setting strategy (C). If participants do pursue this option, then—after dragging non-target circles to the bottom of the box (D-E)—the new location of the target circles will remind them of the required action (F). Reprinted from Child Development, 89 (6), Redshaw et al. Development of Children's Use of External Reminders for Hard-to-Remember Intentions, 2099-2108, Copyright (2018) with permission from John Wiley and Sons. Child Development © 2018 Society for Research in Child Development, Inc. All rights reserved. 009-3920/2018/8906-0015.

### 7.3.1. The power of metaforesight

Appreciating that the future may not pan out according to their best-laid plans, people frequently establish diverse contingencies and 'if-then' conditionals – much to their benefit (and to the profit of insurance salespeople). Counterfactual thinking about how things *might have been* is a boon to this kind of flexible planning because it lets people simulate how their mistakes might have cost them – and how to avoid repeating errors (S. R. Beck, Robinson, Carroll, & Apperly, 2006; Byrne, 2016; Rafetseder, Cristi-Vargas, & Perner, 2010; Schacter et al., 2015). People also frequently set up choices that are changeable – for instance by keeping receipts so that clothing can be returned if one no longer likes how it looks. In setting out on a clear morning, with fine weather predicted all day, people might nonetheless decide to bring a coat because they realise that their initial sunny outlook (or that of the weather forecaster) could be mistaken.

In the domain of deliberate practice, humans frequently face the problem of deciding *what* skills to try and master given that there is only so much time in a day. *Should I try and master the piano, or pick an easier but perhaps less impressive instrument?* Notably, this can also take the form of 'second-order volitions' – attempting to determine *what we should want,* and, indeed, *wanting to want other things* (Frankfurt, 1988). Together, these processes enable people to become knowledgeable and proficient in vastly disparate areas of mastery. The fact that individuals make such different choices goes some way to explaining why humans are so diverse in their expertise. Indeed, when wired together in reciprocal networks, this range of expertise has accelerated human innovation and potent cooperation, and has played a critical role in our dominance on the planet (Legare & Nielsen, 2015; Suddendorf, 2013).

Most research on the role of metacognition in future-oriented mental time travel comes from the domain of flexible decision-making and willpower. This reflects the practical importance of this question for understanding a vast swathe of unhealthy behaviour in so-called 'impulse-related disorders' including drug use and overeating (Koffarnus et al., 2013): why, exactly, do people often fail to control their behaviours even when they are fully aware of the prospective costs? However, even everyday drug use such as drinking coffee involves, often implicitly, some strategic compensation for one's own future cognitive limitations. One might hope for a perfectly chipper morning meeting, but also realise that without same caffeine this is likely to be little more than wishful thinking. The vast majority of human drug use is not clinically problematic and does not reach the threshold for diagnosis, leading some authors to argue that most drugs are instead used strategically as tools to modify and enhance cognition in various domains (Müller & Schumann, 2011).

On the other hand, people often employ metaforesight to align their anticipated future behaviours with their ‘better judgement’ – as in the akrasia examples discussed earlier. Odysseus, in the archetypal display, has himself lashed to the mast of his ship to prevent an anticipated failure of willpower when he hears the sirens calling (Ainslie, 1975; Boyer, 2008; Elster, 2000). Here, Odysseus realised that an imagined future in which he successfully avoided the sirens was just one way things could turn out, and a dangerous alternative was likely unless he took steps in the present to guard against his future temptations. To do it, he offloaded his cognition – relying on other people in the environment as mechanisms for situational self-control (Duckworth, Gendler, & Gross, 2016). The dieter who, in a cool moment of insight, tells his spouse to hide the cookies is applying the same strategy.

Humans implement such strategies in a form of negotiation with their own future self (Parfit, 1971; Rachlin, 2016; Schelling, 1960; Thaler & Shefrin, 1981). There are apps one can download, for example, that once activated simply block access to various social media, news, and entertainment websites. It is common practice in trying to quit biting one’s nails to apply a clear nasty-tasting liquid so that future failures are punished and corrected by one’s own past compensatory behaviour. A clinical treatment, ‘antabuse’ (*disulfiram*) produces the effects of a hangover immediately after consuming alcohol, and not after the typical delay (Rachlin, 1995; Shelling, 1983). In all of the above cases the common thread is that a future is imagined wherein the person recognizes that their future self will have particular limits – with precursory compensating action a downstream effect of this insight.

Finally, we note that metaforesight may play a particularly crucial role in solving one of the most archetypal future-oriented problems that humans face: how to anticipate and act to satisfy future desires that we currently do not experience (Suddendorf & Corballis, 1997). Indeed, anticipation of future desire states need not necessarily be based on pre-*experiencing* these desire states. Rather, we may often project our *current* drive states and physiological needs into our future selves – and then meta-cognitively recognise that these imagined states are misleading and alter our behaviour accordingly (Redshaw & Bulley, 2018). Thus a fully-sated shopper does not necessarily need to imagine being hungry in order to buy next week's groceries; she merely needs to *know* that she (and the rest of her family) will not be sated in the future.

### 7.3.2. Tools that metaforesight helps to build

As discussed earlier, bifacial hand axes from the Acheulean represent perhaps the earliest hard evidence for complex prospective cognition in any *Homo* species (Hallos, 2005). However, metaforesight allows humans to create still more complex tools – or *cognitive artefacts* – that extend and buttress the mind (Clark, 2008, 2015; Clark & Chalmers, 1998; Donald, 1991; Dror & Harnad, 2008; Heersmink, 2013; Hutchins, 1999; Jones, 2007; Sterelny, 2010; Sutton, 2006). There is some Palaeolithic evidence for representations of landscape features for use in navigation or planning that might fairly be called 'maps' (Clarke, 2013; Smith, 1987), including a recently discovered set of engraved stone blocks from Abauntz Cave in Navarra, Spain dating back approximately 13,000 years (Utrilla, Mazo, Sopena, Martínez-Bea, & Domingo, 2009). The tablets may have been portable, weighing less than the average modern laptop (Clarke, 2013), and thus built in advance to compensate and extend for known limitations in unaided navigation. Interpretations of these engravings and other similar artefacts, such as an 8200-year-old Neolithic "settlement plan map" in Çatalhöyük, Anatolia (Mellaart, 1967), are contentious (Meece, 2006; Woodward & Harley, 1987). We must also consider that maps are most useful if they can be created and used 'on-the-go', and are thus likely to have been produced for thousands of years with transient materials prior to the earliest remaining evidence (Dawkins, 1998). Lines drawn in the sand, however, are famously ephemeral.

Indications of metaforesight in tool use are non-contentious by the time of Babylonian Mesopotamia around 5000 years ago, where evidence for expert cartography abounds, as does cuneiform script (Clarke, 2013; Fischer, 2001; Woodward & Harley, 1987). Maps and writing are of course both excellent evidence that future-directed metacognitive insight and control had emerged because they enable the user to outsource various cognitive processes including memory, mathematics, and even trust. Consider that early recordings of trade and debt took the form of a single marked wooden block called a tally that could be split into two halves – the 'foil' and the 'stock' (Baxter, 1989). Putting both halves back together again in the future to read the inscription would expose any tampering, negating the need for perfect mental accounting of what was sold or owed.

Numerous artefacts abound from diverse cultures that served similar roles, for example the intricate knotted string 'Quipus' used by the Incans and other Andean cultures to store complex records including census and tax information (for multiple other examples see Kelly, 2017). By the rise of ancient Greece, complex water clocks had been developed to keep track of time during political speeches (Dohrn-van Rossum, 1996). All subsequent alarm clocks and external reminders employ the same underlying logic – recognition of, and compensation for, an expected failure of prospective memory.

Once these kinds of complex tools are invented, it becomes fruitful to assess their ability to perform cognitive work in a similar way to how one might evaluate one's own abilities (Risko & Gilbert, 2016). Thus, although one might use Google to help plan the location of a first date, it is inadvisable to use Google *during* the date to help plan the next topic of conversation. Science, as a 'thinking tool' takes this to its extreme: a hypothesis is generated alongside an explicit assessment of its possible incorrectness, and, furthermore, a test that could falsify it (Popper, 1934). Indeed, it is now customary to report metacognitive assessments such as confidence intervals, statistical power and the standard errors of estimates in empirical articles. Scientific instruments are often themselves extensions of sensory apparatuses (like telescopes) as well as tools for the enhancement of cognitive labour (like computers) – but their capacities and uses must be assessed accurately for offloading to be productive (Heersmink, 2016).

People may likewise selectively offload cognitive tasks into other people's minds, for instance when trusting an elder with the details of a creation myth, an experienced tracker to navigate through treacherous terrain, or a spouse with remembering a family appointment (Kelly, 2015; see also Michaelian & Sutton, 2013; Nestojko, Finley, & Roediger, 2013; Palermos, 2016)[5]. There is, however, limited research on how and when people perform prospective cognitive offloading into the minds of other people ('distributed cognition'), or its development in children (though see for example Barnier, Sutton, Harris, & Wilson, 2008; Hirst & Echterhoff, 2012). In further studying social cognitive offloading, it may prove fruitful to borrow from the growing body of work on the role of metacognition in social learning strategies – that is, how people come to 'know who knows' desired information and use that information to learn selectively from others (Heyes, 2016).

### 7.4. Future directions and conclusions

The human imagination facilitates a large array of future-oriented faculties. These include anticipating future emotions, complex planning, preparation for threats, flexible

[5] Andy Clark has gone one step further still, and argues that language itself evolved because it enables people to offload their thoughts into the external environment as perceptible 'objects' that they and other people can then 'use' in further cognition (Clark, 2006).

decision-making, and deliberate practice, all of which are immensely powerful in their own right. However, we have also identified how a capacity for metacognition bolsters these capacities even further. We have proposed "*metaforesight*" – the processes involved in monitoring, controlling, and ultimately augmenting foresight – as an important and understudied parallel of metamemory. The study of this set of processes is in its infancy. There are numerous open questions, such as how metaforesight develops in childhood, what aspects of it are shared with other animals, when and where it emerges in the archaeological record, the nature of its underlying cognitive and neural mechanisms, what factors lead people to use it relative to simpler or less effortful processes, and how it might change in aging and disease. When is it optimal to 'offload' cognition on the basis of our anticipated limits, and does frequent offloading have any negative consequences? Do non-human animals ever place objects strategically to remind themselves of things in the future? Can metaforesight degrade in clinical disorders while foresight remains intact? With the capacity to recognise and reflect on the natural limits of foresight comes the creation of mental, cultural and technological means to compensate for these limits. The human imagination is a tool – and like all tools it is wielded more effectively when you know where its limits lie.

## Chapter Eight. The development of future-directed cognitive offloading

**Bulley, A.**, McCarthy, T., Gilbert, S.J., Suddendorf, T., & Redshaw, J. (Submitted) The development of future-directed cognitive offloading.

**Preface and details of contribution to authorship:**

This chapter presents the results of an experiment into the developmental origins of metaforesight. The experiment showed that even children as young as four years old are capable of rapidly learning to set themselves reminders to compensate for future memory limits. Moreover, the selective deployment of this behaviour in a manner congruent with cognitive demand increased gradually throughout childhood. These findings shed light on how foresight comes to influence decision-making early in childhood. I conceived the idea, designed the experiment jointly with the other authors, and collected all of the data. I analysed the data jointly with Jonathan Redshaw. I wrote the first draft of the paper.

**Abstract**

People often manipulate their environment to facilitate future cognitive performance, for example by setting reminders to aid the execution of delayed intentions. In most laboratory studies of memory, participants are actively prevented from employing such *cognitive offloading* strategies, despite the ubiquity of technology that enables them in everyday life. Here, we assess the early development of future-directed cognitive offloading in a sample of 80 children aged between four and 11 years. Children played a game in which they were required to remember where stickers had been hidden under an array of 25 cups, in order to find them after a short delay. All children completed the task under two difficulty levels, with stickers hidden under either one or five cups. After an initial baseline phase, children were introduced to a reminder setting option involving placing tokens atop the target cups to aid future memory. Even the youngest children were capable of rapidly learning to set reminders to enhance future memory performance and the majority opted to do so. Furthermore, there was a linear increase in selective reminder setting with age, such that older children were more likely than younger children to set proportionately more reminders when there were more targets to remember. These results suggest that, although even pre-schoolers can learn to compensate for future cognitive failures, the selective deployment of this behaviour continues to develop during the primary school years.

## 8.1. Introduction

The ability to anticipate future scenarios and adjust current behaviour accordingly is a hallmark of intelligence. A powerful expression of this ability is that it enables humans to predict their potential cognitive failures and try to preclude these failures. In realising that their memory might fail them, for instance, people often write lists, set alarms, or place items in conspicuous locations to trigger relevant intentions. In this way, people can augment their *prospective memory*: memory for executing specific actions in the future – a capacity that is central to adaptive functioning in everyday life (McDaniel & Einstein, 2000, 2007).

For example, one might need to remember to take a cake out the oven in half an hour. Setting an alarm to sound after the required baking time will guarantee that unanticipated distractions or poor time-tracking abilities do not result in a charred dessert. This reminder-setting behaviour is a type of *cognitive offloading* of mental work into the external environment. It is thought to rely on metacognitive awareness of one's own cognitive limitations (Clark & Chalmers, 1998; Risko & Gilbert, 2016). After all, it is only by recognizing that one may struggle to remember to get the cake out of the oven that compensatory strategies such as setting the alarm will be recognized as helpful and put into action.

Despite its ubiquity and utility in everyday life (J. E. Harris, 1980), the vast majority of studies on memory prevent participants from employing any kind of compensation for their cognitive limits (though see Einstein & McDaniel, 1990) – and for good reason. To study how memory processes generally operate, it is obviously necessary to prevent participants from, for instance, writing down the list of words they have been asked to remember. However, this methodological focus on what can be done in the mind alone does not take into account that people are aware of their limitations and frequently change their environment to improve their performance (Clark & Chalmers, 1998). With the rise of increasingly advanced and common technologies for cognitive offloading such as smartphones there has been a growing rift between laboratory-based tasks that assess unaided cognitive performance and the strategies that people use to solve problems in the real world (Risko & Gilbert, 2016).

Despite the regularity of cognitive offloading in everyday life, very little is known about its nature and development. Young children frequently fail to perform delayed intentions in naturalistic settings (Walsh, Martin, & Courage, 2014), and thus understanding how cognitive offloading develops is also of practical significance. This is particularly relevant in the primary school years as children begin to adopt responsibilities requiring the execution of multiple independent delayed intentions such as household chores (e.g. brushing teeth after waking up, making the bed before leaving the house) and school activities (e.g. bringing home a permission slip, doing homework after class). In the present study we therefore aimed to explore the early development of cognitive offloading: when can children begin to anticipate their possible future memory failures and act to compensate for these future failures in the present?

### 8.1.2. The development of foresight and metacognition

The capacity for prospective cognition develops piecemeal throughout early childhood, with many studies showing that children begin to show evidence for flexible future-oriented problem solving around age four (for reviews see Atance, 2015; Hudson, Mayhew, & Prabhakar, 2011; McCormack & Atance, 2011; Suddendorf, 2017; Suddendorf & Redshaw, 2013). Furthermore, even children as young as three appear to have some metacognitive knowledge about their own memory processes – so-called *metamemory* (Flavell & Wellman, 1975) – including the capacity to appraise what they remember and how well (e.g. Balcomb & Gerken, 2008). For example, by around six or seven years of age, children can effectively distinguish between easier and harder items to learn for a memory test (Dufresne & Kobasigawa, 1989; Lockl & Schneider, 2004). However, it is only by around age nine or ten that children begin to allocate more study time to harder items than easier items. Such findings suggest a distinction between metacognitive *knowledge*, on the one hand, and metacognitive *control,* on the other (Schraw, 1998). While the former refers to processes that enable children to assess their own abilities and knowledge, the latter allows these assessments to be translated into compensatory actions when appropriate (see Dunlosky & Metcalfe, 2008; Dunlosky & Tauber, 2016; Nelson & Narens, 1990).

There have been some initial investigations into the role of foresight (Kretschmer-Trendowicz, Ellis, & Altgassen, 2016) and metacognition (Causey, 2010; Spiess, Meier, & Roebers, 2016) in children's prospective memory performance (see also Atance & Jackson, 2009; Ford, Driscoll, Shum, & Macaulay, 2012; Nigro, Brandimonte, Cicogna, & Cosenza, 2014). However, little is known about when and how children anticipate their memory weaknesses (metacognitive knowledge) and flexibly alter their present action (metacognitive control) when they must remember to perform actions after a delay. Children begin to pass unaided prospective memory tasks from as young as two years old, with performance improving throughout childhood and adolescence (for review see

Kvavilashvili, KyLe, & Messer, 2008). In some studies, children have been introduced to external cues that act as reminders to fulfil delayed intentions (e.g. Guajardo & Best, 2000; Kliegel & Jäger, 2007; Kvavilashvili & Ford, 2014; Meacham & Colombo, 1980; Redshaw, Henry, & Suddendorf, 2016). Typically, however, children have been provided with the reminders by the experimenter, and were not required to generate any cognitive offloading behaviours themselves.

In a previous study, we therefore assessed children's capacity to set their own reminders (Redshaw, Vandersee, et al., 2018). We administered children (aged approximately seven to 12 years) a computerized task in which they could set reminders to aid future memory for a number of delayed intentions. This study was based on a paradigm used to assess reminder-setting for delayed intentions in adult participants (S. J. Gilbert, 2015b, 2015a). Our results suggested that, while children of all ages had metacognitive knowledge that their memory would be worse when there were more future intentions to remember, only the older children set reminders in a manner congruent with task difficulty. In other words, only the older children *selectively* set proportionately more reminders in the difficult condition than the easy condition – thus demonstrating recognition of when the reminder setting behaviour would be most useful or necessary. Although valuable for measuring selective reminder setting in primary school aged children, pilot testing indicated this computerized task was too complex for younger children to perform. Given that many interesting developmental changes in foresight and metacognition take place before age seven, we aimed to develop a simpler game to explore selective reminder setting in younger children.

### 8.1.3. The current study

In the current study we created a simple hiding game paradigm, drawing inspiration from prospective memory tasks (as discussed above) and Piagetian object permanence tasks (Barth & Call, 2006; Piaget, 1954). A circular array of 25 cups was arranged in front of the child. Targets (stickers) were hidden under either one cup or five cups. Participants were instructed to try to find the hidden rewards by choosing the correct cups after a five-second time delay. Children first completed the game without any reminder-setting instructions, and then again after being introduced to an optional strategy with which they could set themselves reminders by placing tokens atop the target cups while the stickers were being hidden. Varying the difficulty of the task (stickers hidden under one or five cups) allowed us to ask the key question about *selective* cognitive offloading: do children set proportionately more reminders when there are more targets to remember? And does this tendency increase with age?

In line with a large literature on the development of children's metacognitive control (e.g. Schneider, 2008), we expected selective reminder setting to increase linearly with age. In our previous study we found that children began to set reminders selectively around age nine (Redshaw, Vandersee, et al., 2018). However, given the substantive differences between that paradigm and the current one, we made no specific predictions about the particular age at which the selective reminder setting behaviour would emerge.

## 8.2. Method

### 8.2.1. Participants

Participants were 80 children recruited at the Queensland Museum, as per our pre-registered data collection plan (41 girls, 39 boys, mean age = 7.39 years, range = 4.01 years to 11.95 years), who participated between April and June 2018. All children spoke English, and most were of a white middle class background. The University of Queensland Health and Behavioural Sciences Human Research Ethics Committee approved the study. Parents or guardians provided verbal or written consent prior to testing, and children received a small gift for participating as well as any stickers they retrieved during the task. Seven additional participants were removed from analysis for falling outside the age range of interest ($n$ = 2), experimenter error ($n$ = 2), parental interference ($n$ = 2), and for unwillingness to complete the task ($n$ = 1).

### 8.2.2. Materials

***8.2.2.1. Apparatus.*** The main apparatus was a field of 25 opaque cups (7cm in diameter) arranged within a 50cm diameter circular board. The cups were placed in two concentric rings, the inner ring consisting of 8 cups and the outer ring consisting of 17 cups (see Figure 8.1, top). The cups in the inner ring were placed at an angle of 45° to one another from the centre of the board, with their centres 11cm from the centre of the board. The cups in the outer ring were placed at an angle of approximately 21° to one another from the centre of the board, with their centres 20.5cm from the centre of the board. The reminder objects were small bright red circular tokens that completely covered the top of the cups. Participants were given a bucket of these tokens (25 tokens in the bucket; one for each cup) at the start of phase two, after the reminder-setting option was explained.

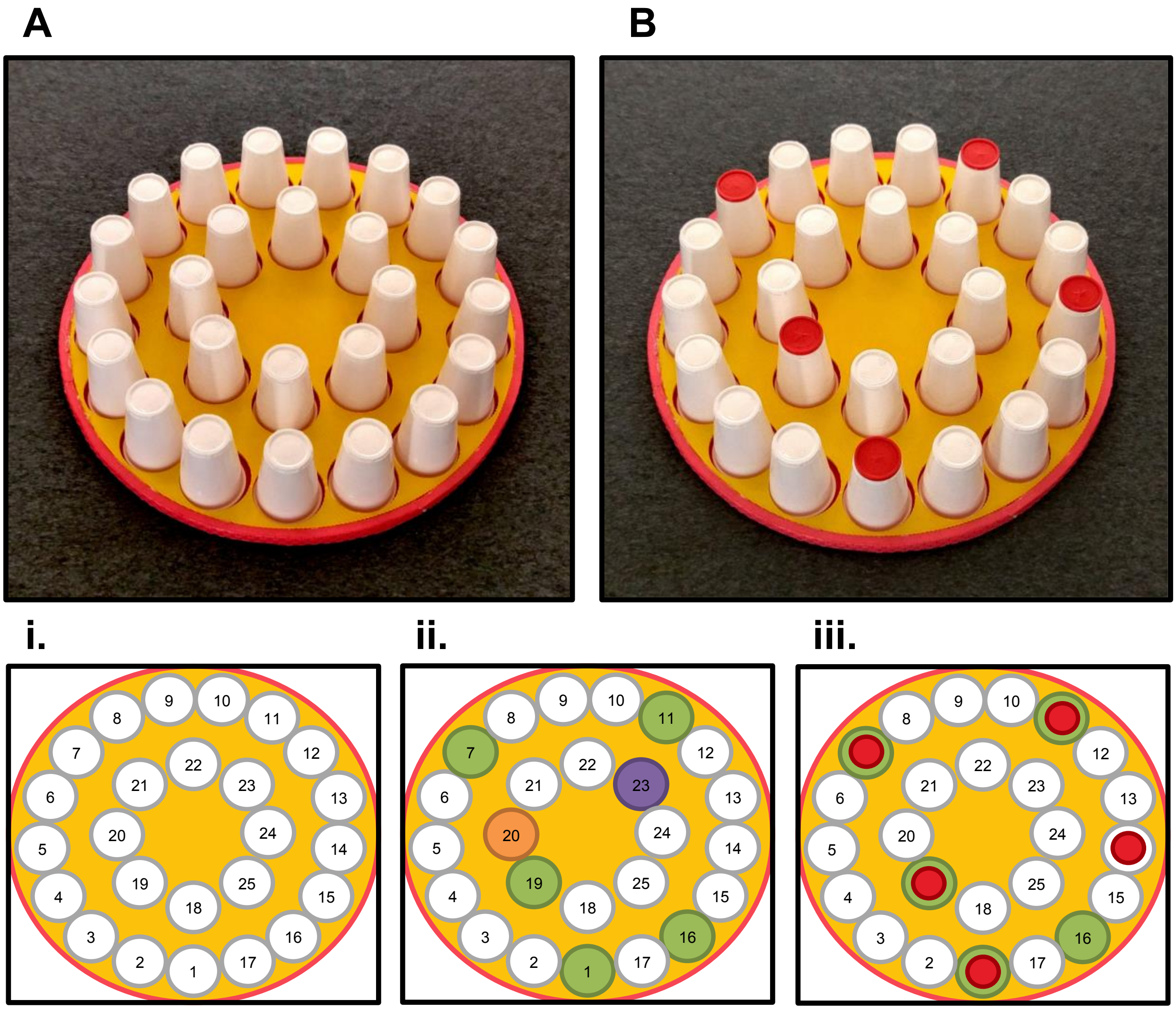



*Figure 8.1.* **A**, The apparatus at the start of all trials. **B**, The apparatus with the reminder-setting tokens placed on the cups in a five-target trial. **i. – iii.**: Example of a five-target trial sequence. **i.**, Participants are presented with the 25 empty upturned cups. **ii.**, The experimenter hides five stickers under a pre-specified pseudo-random selection of cups in a clockwise direction starting with the outside ring (here in order: cups 1, 7, 11, 16, 19 highlighted in green). Both before and after hiding the stickers, the experimenter lifted and replaced a non-target cup without hiding a sticker underneath (here cups 23 and 20), to control for the possibility that participants would simply search and mark cups that the experimenter had touched. **iii.,** In phase two, participants have been introduced to the reminder-setting strategy and are thus able to use the red tokens to cover the target cups while the experimenter is hiding the stickers. In this case, the participant has placed tokens on four of the five target cups, and one of the non-target cups (cup 14).

### *8.2.3.* Design and procedure

This study employed a 2 (difficulty: easy/ hard) x 2 (phase: no reminders phase one/ reminders phase two) within-participants design with age in days measured as a continuous covariate. Participants were given eight trials on the main task. For each trial, the task difficulty was either easy (one target hidden) or hard (five targets hidden), with four trials of each difficulty in total. The order of trial difficulty was counterbalanced between participants (either easy first or hard first), and then alternated within-participants (i.e. 1-5-1-5 vs. 5-1-5-1). The eight trials were broken into two phases of four trials each. In the first phase, no reminder setting strategy was explained to the participant, enabling us to assess baseline performance on the task without cognitive offloading. At the start of the second phase, the reminder setting strategy was introduced (see below). Before the first phase commenced, children were asked a question assessing their metacognitive knowledge into task difficulty across conditions (see 'measures' section).

In the task, the array of 25 inverted cups was arranged in front of the participant in two circles (see Figure 8.1). Targets (stickers) were hidden under the target cups with the cup being picked up by the experimenter in one hand and the sticker being placed underneath it with the other hand before the cup was returned to the board. At this point, a five-second delay commenced (counted down verbally by the experimenter), before participants were instructed to choose which cup or cups they thought had the reward inside. Participants were given the same number of guesses as the number of hidden stickers. When explaining the reminder setting strategy at the start of phase two, participants were told they could place a token on the target cups while the stickers were being hidden to help them remember where the stickers were, and were shown how to use this option. Participants were told the token strategy was completely optional and they could use it if they wanted to, but that they did not have to. Six participants had the reminder-setting strategy explained again after the first trial of phase two because they appeared not to understand how to use the tokens or asked for clarification.

### 8.2.4. Measures

***8.2.4.1. Metacognitive knowledge.*** Before completing the main task, children were asked: "Would it be easier to remember where one sticker is hidden, where five stickers are hidden, or would it be the same? What would be easier?" The first two options were counterbalanced, but the "same" option was always presented third before the 'what would be easier' response prompt.

***8.2.4.2. Target search accuracy.*** For each trial, the number of correctly retrieved targets and incorrectly chosen non-target cups was recorded. For easy trials this number was out of one, and for hard trials it was out of five.

***8.2.4.3. Reminder setting behaviour.*** For each trial, the number of target cups and non-target cups that the child marked with the reminder tokens was measured. Non-target cups were cups without a sticker underneath, while target cups were cups under which a target sticker was hidden.

### 8.2.5. Data analysis

Hypotheses, measures, and our analytical plan were pre-registered with the Open Science Framework: https://osf.io/k48dx/. All statistical analyses were performed in SPSS 24.

## 8.3. Results

### 8.3.1. Target search accuracy

Children's target search accuracy was operationalized as the proportion of target cups searched after the delay (out of all cups searched), such that scores could range from 0 (i.e., no target cups searched) to 1 (i.e., all target cups searched). This score was averaged across the two trials of each difficulty (easy vs. hard) within each phase (no reminder setting vs. reminder setting). Accuracy was analysed with a repeated-measures ANCOVA including within-subjects factors of difficulty and phase, along with age as a continuous mean-centered covariate.

As seen in Figure 8.2 (Panels A and B), this analysis revealed significant main effects of phase, $F(1,78) = 32.34$, $p < .001$, $\eta_p^2 = .29$, difficulty, $F(1,78) = 93.92$, $p < .001$, $\eta_p^2 = .55$, and age, $F(1,78) = 14.62$, $p < .001$, $\eta_p^2 = .16$. Accuracy was higher when participants could set reminders in phase two ($M = .82$, $SE = .03$) than when they could not in phase one ($M = .70$, $SE = .02$), and in easy trials ($M = .86$, $SE = .03$) than in hard trials ($M = .66$, $SE = .03$). Accuracy was also higher with increasing age, $r(78) = .40$. These main effects were qualified by a significant phase x difficulty interaction, $F(1,78) = 32.56$, $p < .001$, $\eta_p^2 = .29$, and a significant phase x difficulty x age interaction, $F(1,78) = 4.66$, $p = .034$, $\eta_p^2 = .06$. The two-way interaction indicated that the difference in children's accuracy between easy and hard trials was larger when children could not set reminders ($M_{diff} = .30$, $SE = .03$, $p < .001$) than when they could set reminders ($M_{diff} = .11$, $SE = .03$, $p < .001$).

The three-way interaction indicated that this narrowing of the easy vs. hard performance gap between phases was greater in the younger children than the older children.

### 8.3.2. Reminder setting

In the reminder setting condition 63 out of 80 children (78.75%) used tokens to mark at least one cup on at least one trial with 61 out of 80 (76.25%) marking at least one target cup, and 8 out of 80 (10%) marking at least one non-target cup. Out of all the tokens that were placed on cups, 96.44% were placed on target cups, suggesting that children firmly understood the reminder setting strategy.

Children's reminder setting scores were operationalized as the difference between the proportion of target cups marked and the proportion of non-target cups marked (similarly to S. J. Gilbert, 2015b, 2015a; Redshaw, Vandersee, et al., 2018). The rationale for this measure is that participants occasionally placed tokens on non-target cups, which of course does not constitute accurate reminder setting. By subtracting the likelihood of marking non-target cups from the likelihood of marking target cups, we can obtain a measure of reminder setting behaviour that is selectively directed toward target cups – corrected for any general tendency to mark cups. Participants' reminder setting scores could range from -1 (i.e., in the unlikely case that a child marked every non-target cup but no target cups) to 1 (i.e., in the 'perfect' case that a child marked every target cup but no non-target cups). A participant who did not mark any cups on a given trial received a score of 0.

This measure was entered into an ANCOVA including the within-subject factor of difficulty (easy vs. hard), along with age as a continuous, mean-centered covariate. The analysis showed a significant effect of difficulty, $F(1,78) = 54.56$, $p < .001$, $\eta_p^2 = .41$, such that children had a higher reminder setting score in the hard trials ($M = .54$, $SE = .05$) than in the easy trials ($M = .19$, $SE = .04$). The main effect of age was not significant, $F(1, 78) = 2.17$, $p = .145$, $\eta_p^2 = .03$, such that children's average reminder setting scores across all trials did not vary as a function of age. As predicted, however, there was a significant difficulty x age interaction, $F(1,78) = 5.78$, $p = .019$, $\eta_p^2 = .07$, such that the tendency to have a higher reminder setting score in the hard trials than the easy trials increased with age.

These findings are illustrated in Figure 8.2 (Panels C and D). Even the four- and five-year-old children showed evidence of selective reminder setting at the group level, such that they had a significantly higher reminder setting score in hard trials than easy trials, $p = .040$, $\eta_p^2 = .05$; although the size of the effect was larger in the older children, all other $p$ values < .001, $\eta_p^2$ values ranged from .15 to .22. This effect appeared to be driven by age-related differences in the easy condition rather than the hard condition. Indeed, reminder setting scores on easy trials significantly decreased with increasing age, $r$ (78) = -.33, $p$ = .003, whereas reminder setting scores on hard trials did not significantly correlate with age, $r$ (78) = .02, $p$ = .883.

### 8.3.3. Metacognitive knowledge

Overall, 52 out of 80 children (65%) correctly answered that it would be easier to find where one sticker was hidden than where five stickers were hidden when asked before the game (24 children incorrectly answered that five stickers would be easier, and four children incorrectly answered that both tasks would be the same difficulty). A binomial test compared children's performance against a chance level of 33.3%. This test revealed that children performed significantly better on the metacognitive knowledge question than would be expected by chance alone, $p$ < .001. There was, however, no significant correlation between this answer and age, $r$ (78) = .10, $p$ = .369, nor was there a significant correlation with the Selective Reminder Setting Index (see Figure 8.2, Panel D), $r$ (78) = .16, $p$ = .157.

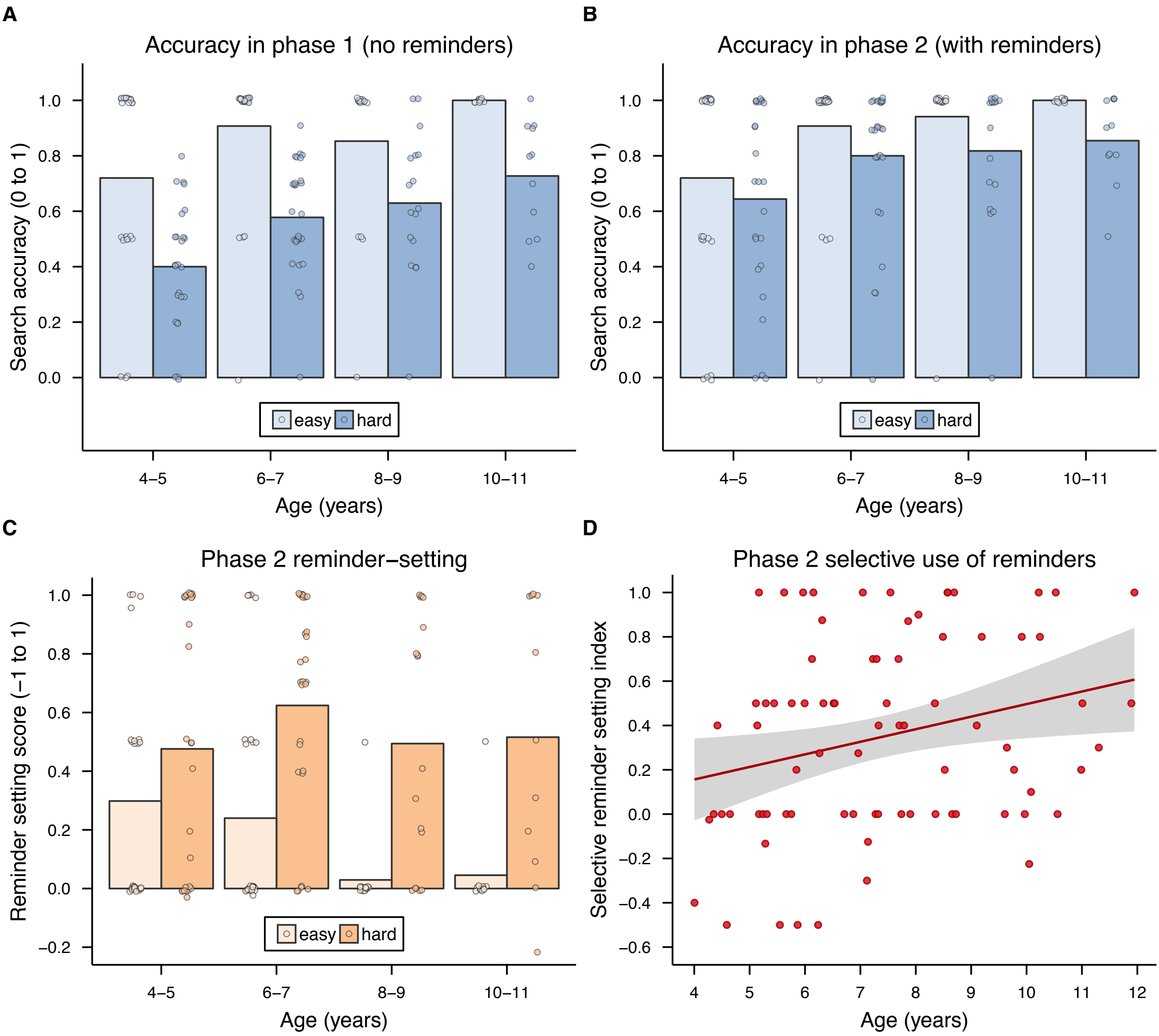



*Figure 8.2.* **A, and B,** Children's search accuracy across ages, difficulty level, and phase. **C,** Reminder-setting scores in phase two. The difference in reminder setting scores between easy and hard trials increased with age. For plots A-C, In order to visualise the results, participants have been divided into four age groups: 4/5-year-olds (*n* = 25), 6/7-year-olds (*n* = 27), 8/9-year-olds (*n* = 17), and 10/11-year-olds (*n* = 11) – but note that the formal statistical analyses treated age as continuous. The raw data is overlaid and minor jitter has been added to aid discrimination between data points. **D,** The age effect was visualised by creating a Selective Reminder Setting Index (SRSI) for each child. The SRSI was calculated by subtracting the reminder setting score for easy trials from that of hard trials, such that scores above zero indicated selective reminder setting. The correlation between age and the SRSI was significant, $r$ (78) = .26, $p$ = .019. The grey band around the line represents the 95% confidence interval.

## 8.4. Discussion

This study aimed to explore the development of future-directed cognitive offloading. Children performed a memory game in which they were required to remember the location of either one or five hidden items under an array of locations to find those items after a five-second delay. After being taught a reminder-setting strategy, participants could choose to employ this option to aid their future memory performance. Children of all ages frequently chose to use the reminder setting strategy after this minimal instruction, and performance in the memory game was significantly improved when participants could do so. However, the tendency to set proportionately fewer reminders when there were fewer items to remember increased with age, and from around eight years of age children almost never set reminders in the easy condition (see Figure 8.2, Panel C).

These results indicate that even children as young as four years old can rapidly learn to offload cognitive demands into the external environment in order to facilitate future memory performance, and that the choice to do this selectively in line with task demands increases throughout development. This study therefore points towards the early developmental origins of the use of *cognitive artefacts* (Sterelny, 2010). The tokens in the reminder setting task can be thought of as an external and symbolic representation of the hidden location of the stickers (Heersmink, 2013), while placing these symbols atop the hiding locations is an "intelligent use of space" that improves cognitive performance (Kirsh, 1995). It seems that early in the preschool years, children can readily learn to modify their surroundings to make thinking easier, and in this way they create the early scaffolding for an "extended mind" (see Clark & Chalmers, 1998; Hutchins, 1999).

The findings of the current study are also broadly consistent with results from a recent series of experiments on children's capacity to prepare for two alternative future possibilities. When preparing to catch an item that could exit from two possible locations, many four-year-old children spontaneously and consistently prepare for both outcomes (Redshaw, Suddendorf, et al., 2018; Redshaw & Suddendorf, 2016; Suddendorf et al., 2017). One interpretation of this finding is that children of this age understand that their predictions of future outcomes can be *incorrect*, and that therefore it is worth preparing for alternative possibilities as well (see Bulley, Redshaw, & Suddendorf, 2019; Redshaw, 2014). Similarly, one interpretation of the current task is that many four-year-old children understand the limits of their future memory performance and set reminders to preclude the anticipated cognitive failure. Future research may therefore wish to examine relationships between children's performance on these tasks. For further discussion on the relationship between elements of episodic foresight/ episodic future thinking and prospective memory see Atance & O'Neill, (2001), Brewer & Marsh, (2010), Nigro et al., (2014), Schacter, Benoit & Szpnar (2017), and Terrett et al., (2016).

### 8.4.1. Selective reminder setting increases with age

The developmental pattern of selective reminder setting in the current task was considerably different from that observed in the task from our previous reminder-setting study (Redshaw, Vandersee, et al., 2018). In that study, children did not demonstrate evidence of selective cognitive offloading until around age nine, whereas in the current study it was present in children as young as five (see Figure 8.2, Panel D). One likely explanation for the difference is as follows: because the easy trials of the current task were *particularly* easy, younger children felt more confident in their ability to pass these trials *without* the use of reminders. Indeed, passing easy trials only required children to hold one visually-displaced target location in mind during a fixed five-second delay, with no other ongoing tasks to distract them. In the earlier study, however, the easier trials of the computerised task required children to hold in mind one target stimulus *and* one target direction (left, right, or up), whilst also performing an ongoing task with a short but variable delay. Thus, younger children in that study may have been more likely to use reminders in the easy condition "just in case" of future memory failure. Indeed, the age-based difference in selective reminder setting in the previous study appeared to be primarily driven by older children setting relatively more reminders in the hard trials than younger children, whereas in the current study it was entirely driven by older children setting relatively fewer reminders in the easy trials than younger children.

One might ask whether it is also possible that the effect of age on selective reminder setting in this study was simply because younger children were in fact worse at remembering the location of a single target in the easy trials, and appropriately set more reminders on these trials. After all, the four- to five-year-olds were not perfectly accurate in the easy trials when reminders could not be set (see Figure 8.2, Panel A). This explanation seems unlikely, however. Consider that children aged six to seven performed just as well as older children on the easy trials when they could not set reminders (again see Figure 8.2, Panel A). Still, these children set reminders much more frequently than older children on the easy trials when they were able to do so (see Figure 8.2, Panel C). This suggests that younger children were not simply setting more reminders in the one target condition because of poorer memory capacity. It is nonetheless possible that children's *confidence* in their unaided memory does change with age, and this is an important avenue for future research.

Another potential alternative explanation is that the younger children simply preferred playing with the tokens, or were more likely to imitate or obey the experimenter instructions. However, the reminder setting score in the hard condition was equally high across the age groups (but not at ceiling) – such that there was no general tendency for younger children to use tokens more than older children. Instead, we tentatively interpret the current results to mean that children's capacity to selectively employ reminder setting increases with age throughout the primary school years. Importantly, this change may be principally driven by an increased understanding of situations in which reminder setting is *unnecessary* – i.e., when one's own internal cognitive processes alone are sufficient to execute the delayed intention with high probability.

If this interpretation is correct, it indicates that as children get older, they get progressively better at flexibly choosing an appropriate cognitive offloading strategy based on the particular demands of the situation. This is in line with much prior literature on the gradual development of metacognitive knowledge and metacognitive control, particularly from the field of metamemory (e.g. Dufresne & Kobasigawa, 1989; Lockl & Schneider, 2004). Notably, we found no significant relationship between children's assessment of task difficulty and selective reminder setting. Furthermore, although we found that selective reminder setting significantly increased with age, we found no relationship between children's assessment of task difficultly and age. It is worth noting that the metacognitive knowledge measure was a verbal self-report question and must therefore be interpreted with caution (for previous self-report studies of children's insight into reminder setting strategies see Beal, 1985; Kreutzer, Leonard, & Flavell, 1975). For instance, children may have been biased against choosing the "same" option because of the particular phrasing of the response prompt that may have implied a dichotomous choice. Still, while null results are always difficult to interpret, this pattern of findings is broadly consistent with the notion that metacognitive knowledge and control are distinct cognitive processes, with the former typically developing prior to the latter.

### 8.5. Future directions and conclusions

The experimenter occasionally observed interesting spontaneous uses of reminder-setting strategies *before* the second phase in which the token reminder setting strategy was explained. For example, children were observed placing their fingers atop cups under which the stickers were hidden, or staring intently at a target cup – possibly in order not to let distractions arise that might cause them to forget the hiding locations. These are presumably just some examples of a diverse repertoire of natural and spontaneous behaviours that children and older humans employ on a daily basis to offload cognition in the context of compensating for potential memory failures. Future studies should attempt to document and categorize how people innovate their own cognitive offloading strategies, as well as chart the use of such strategies in experimental contexts where participants are not explicitly introduced to any offloading options.

It will also be important to explore any potential differences between the deployment of reminder setting options that are taught to participants (as per the present study) and the use of those strategies that participants generate themselves. Recent evidence shows that adults' reminder setting is predicted by low confidence in unaided ability both when the strategy is instructed and when it is spontaneously generated (Boldt & Gilbert, in prep). However, the developmental origins and cognitive predictors of spontaneous cognitive offloading remain understudied.

The capacity to compensate for anticipated failures is a central feature of the human cognitive toolkit (Bulley et al., in press). It underpins diverse phenomena from contingency planning for alternative possible futures, to the invention and use of symbolic cognitive artefacts such as clocks, maps, and written scripts. The present findings suggest that the basic capacity to learn and selectively adopt offloading strategies to preclude cognitive failures can be an early-acquired skill that continues to develop throughout early and middle childhood.

## Chapter Nine. General discussion

### Preface and details of contribution to authorship:

In this general discussion, I summarise the main insights gleaned from each of the preceding chapters in the context of a review of key themes. I suggest avenues for future research into the mechanisms and development of prospection in decision-making, as well as the clinical relevance of the findings in this thesis. Lastly, I reflect more broadly on the evolutionary legacy of prospective cognition in human decision-making, and explore ways it could be leveraged to better steer us forwards. I am the sole author of the chapter, with some of the text adapted from a review article (Bulley, 2018).

## 9.1. Keeping the future in mind

Prospective cognition enables humans to anticipate future possibilities and to thereby guide decision-making in the present. This thesis has been an attempt to explore this influence of foresight on decision-making, in terms of underlying psychological mechanisms, cognitive development, clinical relevance, and evolutionary history. I have presented the results from a number of empirical studies alongside novel theoretical perspectives that serve to tie together disparate approaches to core questions. In this chapter, I survey the key themes of the thesis with close reference to the insights gleaned in specific chapters, alongside suggestions for important future directions. First, I discuss the general role of imagining the future in intertemporal decision-making, including the underlying mechanisms and potential for clinical application. I then discuss the interface of emotion and prospection in anxiety, with reference to both the evolutionary benefits and subjective costs of this interface. In a final section, I trace the functions of prospection in adaptive human decision-making with reference to the capacities of other animals and child development. I argue that together these functions are central to understanding the evolutionary success of our species, and I finish with some thoughts on how leveraging them will be critical for safeguarding our continued existence moving forward.

## 9.2. The role of imagining the future in intertemporal decision-making

Humans, like all animals, must make intertemporal trade-offs because of the causal direction of time: many decisions have outcomes that play out only after a substantial delay (Berns et al., 2007; Stevens & Stephens, 2008). When we speak of a person being prudent, judicious, or wise, we are usually speaking of their tendency to *take into account* and *appropriately prioritise* such delayed outcomes. A central issue examined in this thesis has been the extent to which a tendency to account for delayed consequences is underpinned or influenced by mental time travel. In chapter two, I presented an integrative theoretical model of prospective cognition in intertemporal choice (Bulley, Henry, et al., 2016). I argued that while intertemporal choices can be made without any episodic foresight whatsoever, imagining future scenarios enables more flexible and adaptive intertemporal decision-making. This model places anticipated emotional value and likelihood centre-stage as sources of information that modulate intertemporal preferences. When a future event is imagined, information about the nature of the future is fed back into the decision-making processes involved in prioritising behavioural effort towards immediate and delayed rewards. One prediction derived from this model is that imagining the future should have different effects depending on the nature of the future that is envisaged – for example, if the future is foreseen as dangerous, bleak or uncertain then this may encourage the prioritisation of immediate rewards.

In the past few years there have been a number of explorations of the effects of cued episodic foresight on intertemporal choice (for recent reviews see Benoit et al., 2018; Rung & Madden, 2018b; Schacter et al., 2017). These included chapters three and six of this thesis. In chapter three, it was shown that cuing episodic foresight reduces delay discounting in a monetary intertemporal choice task, but has only small and marginal effects on alcohol-related decision-making. The effect of cued episodic foresight on delay discounting was replicated again in chapter six with the largest sample to date in any study of this effect. The main insight from these two behavioural studies of the role of cued episodic foresight is that the attenuating effect appears to be limited to certain dimensions of impulsive choice – perhaps only those with a choice structure that contains an explicit time dimension. In other words, despite the effect of cued episodic foresight on monetary delay discounting (choices between smaller sooner, and larger later monetary rewards), the effects do not appear to extend universally to other constructs under the impulsivity umbrella. In particular, I reported in chapter six how cued episodic foresight did not affect behavioural risk-taking in a standard laboratory task, the balloon-analogue risk task. It may be informative to adapt decision-making tasks like the BART to make them future-oriented, and thereby observe if this makes them susceptible to the effects of cued episodic future thinking. I also discovered that the valence of the cues did not change the nature of the effect – imagining both positive future events and future threats led people to prioritise delayed rewards and reduced delay discounting. This capacity to imagine future threats is a crucial adaptive element of human foresight, and I discuss it in depth in the following section.

The findings in this thesis add to a large body of other work that has begun to trace out the boundaries and moderators of the effect of cued episodic foresight in intertemporal choice. For instance, it has been found that the episodic cuing effect is more pronounced when events are imagined with greater vividness (Palombo et al., 2015; Peters & Büchel, 2010), when the events are more personally or emotionally relevant (Benoit et al., 2011), and amongst participants who scored greater on a drive scale that measured persistent pursuit of goals (Daniel et al., 2013a). The effect is less pronounced amongst participants with lower short-term visuospatial working memory capacity (H. Lin & Epstein, 2014), and those who scored higher on a self-report measure of consideration of the future, such that the cuing effect was particularly effective for participants who were less prone to usually consider the long-term consequences of their actions (Benoit et al., 2011). The effect also seems to be somewhat dependent on the content of the thoughts (if not the affective valence, as reported in chapter six). The size of the cuing effect does not appear to depend on the level of familiarity of the content (i.e. imagining a meeting with a personally known and not personally-known individual), however it is worth noting that these ostensibly similar effects appeared to rely on different underlying neural mechanisms (Sasse et al., 2015)[6]. Furthermore, O'Donnell et al. (2017) report that positive episodic future event cues pertaining to participant's personal financial goals reduced delay discounting to a greater extent than general positive episodic future events. Similarly, one study found that the cueing effect on delay discounting was comparable for food-related and general events, but episodic cues only reduced caloric intake if those cues were food-related (Dassen et al., 2016).

Despite this surge of interest in the scope of the episodic cuing effect, its boundary conditions, and its moderating variables, the underlying psychological mechanisms remain unclear. In chapter six, I outlined various possibilities. These possible explanations include a generic change in future orientation or a general increase in deliberative cognition bought about by episodic foresight. They also include preparatory and motivational salience triggered by the imagination of delayed requirements, implicit or explicit priming from the cues themselves, and demand characteristics whereby participants devise and act in line with the experimental hypotheses (Rung & Madden, 2018a). In chapter six, I also critically evaluated these various explanations and made some suggestions for future avenues by which they could be tested.

There have also been some findings about the underlying neural mechanisms of the effect since the initial studies (Benoit et al., 2011; Peters & Büchel, 2010). For example, Hu et a., (2017) replicated the involvement of a hippocampal-medial prefrontal cortex connectivity pathway (as discussed in chapter two), and further reported that the functional connectivity associated with episodic *memory* capacity was also associated with the reduction of discounting during cued episodic foresight. This tentatively implicates individual differences in the neural underpinnings of episodic memory capacity in the tendency to derive a reduction in discounting using foresight. Speculatively, this supports the notion that episodic memory and episodic foresight are both forms of an underlying

[6] Note that the same could be true of the ostensibly similar observable effects of positive and negatively valenced foresight reported in chapter six.

episodic construction system (Hassabis & Maguire, 2009; Schacter et al., 2012) that generates scenes and narratives in mental time travel (S. Cheng et al., 2016; Suddendorf, 2013). Lesion and neuroimaging studies have also implicated the ventromedial prefrontal cortex as a key node in the effect of foresight on decision-making, on account of its role in creating mental scenarios through the integration of details, or in imbuing imagination with emotional salience (Benoit et al., 2014; Campbell, Madore, Benoit, Thakral, & Schacter, 2017; Sellitto et al., 2010; Sellitto, Ciaramelli, & Di Pellegrino, 2011). While the hippocampus has long been situated at the heart of mental time travel, lesion studies have now also begun to help trace out the precise role of episodic foresight in intertemporal choice, as discussed in chapter two (Kwan et al., 2012; Kwan, Craver, et al., 2015; Palombo et al., 2016).

### 9.2.1. Future-directed capabilities without foresight

Preparation for the future is ubiquitous in living organisms. Think back to the spider from the opening pages of this thesis, whose diligent web-building efforts only reap rewards after a significant delay and investment of effort in the present. This spider is engaging in prospection if we take a loose definition of the term that encompasses all future-oriented cognitive and behavioural processes. Many such future-directed processes are the result of mechanisms such as instinct, fixed action patterns, and associative learning. Indeed, all associative learning is essentially future-oriented in that an animal learns what to expect on the basis of violations to previous predictions (Suddendorf & Corballis, 2007). With others, I have argued elsewhere that it is worth distinguishing these kinds of simple prospection from more complex prospection such as the episodic foresight that characterises mental time travel into the future (Suddendorf et al., 2018). In any case, it suffices to say that there are many potential mechanisms by which present decision-making can be modified to accord with future consequences.

In chapter five of this thesis I conducted a cross-country analysis into the role of environmental threat in intertemporal decision-making. I found that lower life expectancy in a given country was associated with both a smaller percentage of people willing to wait for a larger but delayed reward, as well as a younger age at first birth for women in that country. These results held after controlling for region and economic pressures (GDP-per capita), and while interpretations are riddled with difficulties at the cross-country level (e.g. Kuppens & Pollet, 2014), the results have also since been replicated at the between-individual level (A. J. Lee, DeBruine, & Jones, 2018). In this replication, the results were essentially the same when the level of analysis was individuals within countries rather than between countries (and for another recent extension of these findings see Martin, Branas-Garza, Espín, Gamella, & Herrmann, 2018). The results dovetail with a number of other findings from the individual level – such as those showing steeper delay discounting amongst people who have been exposed to natural disasters, violence and death (see papers cited in Pepper & Nettle, 2017) – to suggest that potential environmental threat is an important predictor of intertemporal decision-making (see also Jacquet et al., 2018). As discussed, the mechanisms by which people modify their decision-making in line with prospective risks remain opaque. The body of current findings do not uncover the genetic, phylogenetic, developmental, cultural, or psychological mechanisms that might underpin this shift. Nonetheless, various plausible (and potentially intersecting) proximate accounts have been put forward including developmental plasticity (Frankenhuis et al., 2016), implicit adjustment on the basis of external cues (Pepper & Nettle, 2017) and explicit mental reasoning or planning as enabled by mental time travel into the future (Bulley, Pepper, et al., 2017)[7]. These various explanations for within-individual shifts in delay discounting predict the presence of more variation in relatively less consistent or stable environments, notwithstanding the high heritability and generally observed stability of the trait across the lifespan.

### 9.2.2. Applicability and clinical relevance

Aside from lower life expectancy across countries, preference for immediate relative to delayed rewards has been associated with substance use disorders (Story et al., 2014), obesity (Amlung et al., 2016), gambling (Wiehler, Bromberg, & Peters, 2015), and a range of other potentially maladaptive decision-making patterns (Daugherty & Brase, 2010). The etiological role of delay discounting in these circumstances is supported by longitudinal studies (see papers cited in Rung & Madden, 2018b). Given such findings, steep delay discounting has therefore been identified as an important "trans-disease" behavioural health marker (Bickel, Jarmolowicz, Mueller, Koffarnus, & Gatchalian, 2012; Koffarnus et al., 2013), and is a prime target for intervention (J. C. Gray & Mackillop, 2015). There has

[7] The question of mechanism relates to an important theme: that of building bridges between 'low-level' prospection as instantiated in, for example, reinforcement learning, and that of 'higher-level' prospection in the case of mental time travel into the past and future. The relationship between these levels of analysis is an important direction for future research (see Bulley, 2018). Note that there have been some recent attempts to address even "high-level" concepts like "optimistic beliefs" (Sharot and Garrett 2016), and explicit "intertemporal choice" at the "low-level" of reinforcement learning (Lefebvre et al. 2017; Solway, Lohrenz, and Montague 2017).

thus been some considerable excitement about the possibility of harnessing prospection to modify discounting-related behaviours that lead to negative health outcomes (for a systematic review see Rung & Madden, 2018b). Cuing episodic foresight has now been found to reduce ad libitum caloric intake (Daniel et al., 2015, 2013b), cigarette smoking (J. S. Stein et al., 2016), and, marginally, certain indices of alcohol demand as seen in chapter three of this thesis (and see also Snider et al., 2016).

With this all said it is important that these effects are interpreted with caution. Furthermore, the potential limits of episodic cuing must also be carefully delineated. As discussed above, I have shown in this thesis that while there is robust evidence of the effect of cued episodic foresight on monetary intertemporal choice, this cuing effect does not necessarily extend robustly to other decision-making domains such as alcohol purchasing (chapter three) or risk-taking (chapter six). There is also some preliminary evidence that the cuing effect does not affect delay discounting in older adults, and that older adults with poorer attentional control are less likely to show reduced discounting from cuing (Sasse et al., 2017). While this neuroimaging study had a small sample, the results suggest that older adults may not derive the episodic cuing effect because of decline to attentional control ability. It is also possible that older adults have a reduced ability to generate the episodic detail required for the effect. This is made more plausible on account of the well-reported shifts in episodic and semantic details during imagining in older adults and other age- and dementia-related deficits in episodic foresight (Addis, Roberts, & Schacter, 2011; Lebreton et al., 2013; Lyons et al., 2014).

Before prospection cuing is integrated into treatment interventions (e.g. for substance use disorders), further research should be done on the populations in which it may be effective, as well as the underlying mechanisms as discussed above. One important question to address is whether there are ways to bolster or increase the episodic cuing effect and generalise it to populations who would otherwise not benefit from it. For example, to elicit the effect in older adults or those with dementia it may be possible to augment the episodic detail of imagined future events. This could thereby circumvent the decline in internal details responsible for the lack of the cuing effect. Recent evidence suggests the possibility of using an interview-based cognitive intervention called an *episodic specificity induction*, which has been shown to enhance the provision of internal episodic details in younger and older adults by focussing participants on detailed elements of a previously viewed scene (Madore, Gaesser, & Schacter, 2014; Madore, Jing, & Schacter, 2018; Madore, Szpunar, Addis, & Schacter, 2016). The logic behind this manipulation is that it selectively enhances performance on tasks that require episodic simulation but does not enhance performance on tasks that require other kinds of prospection. Thus, if implementing an episodic specificity induction in an intertemporal choice paradigm with episodic cues were to enhance the cuing effect, this would shed light on the respective role of episodic processes in the effect. Finding ways to ensure the cuing effect is efficacious in various clinical groups is particularly important if it is to be rolled out as an intervention, considering the decision-making shifts (and correspondent functional impairments in everyday life) observed in various psychopathologies and dementias (for review see Gleichgerrcht, Ibáñez, Roca, Torralva, & Manes, 2010). It will also be imperative to more broadly examine what situations and contexts, external to the individual, promote and hamper decisions that take the future into account.

### 9.3. Evolution, prospection, deterioration, and psychopathology

> Life had overshot its target and blown itself apart. A species had been too heavily armed — its genius made it not only all-powerful in the external world, but equally dangerous to its own well-being.
>
> – PETER WESSEL ZAPFFE, 1933

As discussed in chapters four and seven, human foresight has sometimes been described as costly, in order to underscore the fact that it probably requires a large, densely connected brain, and that such a brain is expensive to grow (Klein, 2013a; Suddendorf & Corballis, 2007). While evidence is limited on the metabolic 'costs' of cognition per se, the general arguments can be levelled as an extension of the common claim that brains for supporting more flexible behaviours cost more resources to build and maintain than those that have more wired in processes such as fixed action patterns that activate upon particular stimulus cues in the environment[8]. At each stage in its evolutionary phylogeny, we must therefore assume that the reproductive benefits of a capacity for prospection outweighed whatever costs it entailed.

However, aside from the cost of development and operation, there is another potential cost to any highly complicated mechanism with many 'moving parts': it can break

[8] The Sphex wasp *Sphex ichneumoneus* has become representative of the archetypal 'fixed' creature, whose routine to clean out her burrow before bringing her cricket prey inside will be repeated *ad infinitum* if the cricket she has left at the threshold is repeatedly moved a few inches away from the entrance. Some see this so-called "*sphexishness*" as the antithesis of 'intelligence', 'mindedness' or 'foresight' (Dennett, 1984; Hofstadter, 1982) – though interestingly this anecdote may be somewhat apocryphal and kept alive because of its rhetorical usefulness (Keijzer, 2013).

down or malfunction in various ways (Bulley & Irish, 2018; Henry, Addis, Suddendorf, & Rendell, 2016; Irish & Piolino, 2016). For example, deterioration to the key neural networks involved in episodic simulation in Alzheimer's disease produces marked deficits in the ability to imagine specific personal events (for review see Irish & Piolino, 2016). However, it is thus far unclear what precisely causes these detriments, or how they relate to impairments in activities of everyday functioning. Considering the critical *functions* of prospection outlined in this thesis, I view this latter question about the consequences of its *dysfunctions* to be of utmost importance in clinical settings (see Brunette, Calamia, Black, & Tranel, 2018 for some initial investigations).

It is also important to note that evolutionary costs and benefits to an organism are not the same as the costs and benefits to its subjective well-being. Peter Wessel Zapffe (1933) observes that the "genius" of human beings is also a source of great suffering. This may also be true about the "genius" of foresight. It provides us not only with extraordinary powers, but also gives us the best seats in the house to mentally access futures we would rather not foresee: those that include ruin, suffering, and the death of loved ones and ourselves. Varki (2009) suggests that for mechanisms allowing this mental access to have evolved at all, simultaneous systems for self-deception would have been required to offset the negative consequences such dread would engender for adaptive behaviour (see also von Hippel & Trivers, 2011). Whether or not this is true, it is worth considering that human prospection is situated at the heart of psychopathology. Indeed, a full treatment of the various clinical disorders in which prospection is implicated lies far beyond the scope of this thesis (Brüne & Brüne-Cohrs, 2007; Henry et al., 2016; Holmes, Blackwell, Burnett Heyes, Renner, & Raes, 2016; Holmes & Mathews, 2010; Ji et al., 2016; Jing et al., 2016).

In many clinically-relevant circumstances, such as in affective disorders, the mechanisms of prospection appear not to be damaged *per se* like they are in dementia, but instead exhibit shifts in content or format (for reviews see Macleod, 2017; Moustafa, Morris, & Elhaj, 2018; Schacter et al., 2008). In this thesis, I have focussed mostly on anxiety – which can be conceived as a type of prospective emotion geared towards the management of potential threats. As outlined in chapter four, I argue that anxious emotional reactions generate the motivation required to kick-start and maintain defensive behaviour in the face of possible dangers (Miloyan et al., 2018; see also Miloyan, Bulley, et al., 2016). In humans at least, this can take place long in advance of potential threats because people can endogenously auto-cue anxiety by simulating a threatening scenario (Benoit et al., 2016; Engen & Anderson, 2018; LeDoux, 2015; Wu et al., 2015). It is therefore not hard to appreciate that anxiety and foresight together act as a potent system for regulating behavioural responses to potential threat (see Nesse & Jackson, 2011).

In chapter four, I presented a taxonomy of threat-related internally generated cognition that describes the various ways humans represent threats in both memory and prospection. This taxonomy divides these representations into semantic and episodic formats. Each of the elements of the taxonomy contributes differently to adaptive threat management in humans, but also to the exacerbation of distressing (clinical) anxiety. A theme of this thesis has been that taking steps to avert anticipated threats is a kind of intertemporal trade-off. Indeed, a great deal of the trade-offs we make in everyday life are construed mentally with this structure: a decision is made in the present that exerts a cost (money, time, or effort), that will later prevent or preclude some other (worse) cost – such as studying hard to prevent failing an exam, or installing alarms to prevent theft. Thus, anxiety can shift intertemporal considerations in such a way as to encourage the prioritisation of immediate action in the face of upcoming dangers, despite the myriad costs of preparation (Miloyan, Bulley, et al., 2016). An important direction for future research will be to trace out the similarities and differences between foresight that represents threats and foresight that represents opportunities. Is the only difference in the valence of the endogenously generated emotion, or might even mechanisms such as retrieval processes differ in each case?

### 9.4. Tracing the functions of the prospective mind: The role of metaforesight

Humans can monitor, control, and ultimately augment their own prospection. We can, for instance, appreciate that a prediction we make could be wrong. This insight enables people to compensate for anticipated limits in various domains. In chapter seven, I argued that this suite of capacities, which could be called *metaforesight*, unlocks additional powers in many of the other functional domains of prospection. For example, appreciating that a representation of the future where willpower is successfully executed is *just one representation* of a possible route forwards, people can perform a *Ulysses pact* by changing their current environment so as to improve their later chances at self-control. This is what leads people to hide the cupcakes when they get home from the supermarket (Duckworth et al., 2016). Representing multiple, mutually exclusive possibilities may also interface with emotion to produce anxiety that motivates preparation for various possible downfalls – such as buying both a lock for one's luggage as well as insurance in case the luggage is stolen altogether even with the lock secured. In the context of prospective memory, which is a crucial capacity that enables people to execute various different intentions at relevant future time points (e.g. remembering to take one's medicines), metaforesight means people can realise that they may not in fact remember unaided. This leads to the invention and utilisation of strategies to overcome anticipated limits (e.g. using a pill box with separate sections for each day). In chapter eight, I explored the early cognitive development of the fundamentals of this ability. Together with another recent study in which I was involved (Redshaw, Vandersee, et al., 2018), this work charts the developmental trajectory of selective compensation for future memory failures for the first time.

I have argued elsewhere that simple developmental paradigms like the ones used in the reminder setting studies of metaforesight might also offer a test-bed for studying deterioration in aging and disease (Bulley & Irish, 2018). This is because developmental paradigms are often minimally verbal, intuitive, and simple to administer. For example, aside from the reminder-setting tasks I have worked on, a recent series of studies with a forked tube (described in chapter seven) have been used to explore the development of the capacity to prepare for mutually exclusive future events – a rudiment of contingency planning (Redshaw & Suddendorf, 2016; Suddendorf et al., 2017). Strategic compensation for anticipated limits, in terms of both contingency planning and cognitive offloading, is an important avenue for future research in clinical contexts because of its centrality to everyday functional activities. It underpins diverse behaviours from arranging insurance to keeping receipts; from packing an umbrella in case it rains to backing-up one's hard-drive; from keeping a calendar to creating a shopping list; and from setting an oven timer to navigating with a GPS – in other words, it is essential.

### 9.5. The evolutionary legacy and future utility of prospection

> The brute is an embodiment of present impulses, and hence what elements of fear and hope exist in its nature – and they do not go very far – arise only in relation to objects that lie before it and within reach of those impulses; whereas a man's range of vision embraces the whole of his life, and extends far into the past and future.
>
> – ARTHUR SCHOPENHAUER, 1851

There has been a long and contentious debate about the nature of non-human animal mental time travel (e.g. Osvath, 2016; Raby & Clayton, 2009; Suddendorf, 2013; Suddendorf & Busby, 2003). In this thesis, I have discussed intertemporal decision-making as one type of prospective cognition, but I have also argued that making simple intertemporal choices does not require any mental time travel whatsoever (chapter two). In related work with Jonathan Redshaw, I recently reviewed the various prospective abilities of animals in a few of the key functional domains that re-occur throughout this thesis. In each domain, we attempted to outline animal abilities and limitations in prospective cognition (Redshaw & Bulley, 2018). These abilities are summarised in Table 9.1. The domains are as follows: (1) navigation and route planning, (2) intertemporal choice and delayed gratification, (3) preparing for future threats, (4) acquiring and constructing tools to solve future problems, (5) acquiring, saving and exchanging tokens for future rewards, and (6) acting with future desires in mind. In each domain, we identify how emerging evidence is showing that non-human animals are capable of considerably more sophisticated future-oriented behaviour than was once thought possible. While explanations for these behaviours remain contentious, in some cases the most parsimonious explanation is to attribute animals with mental representations that go beyond the here-and-now. Nevertheless, we also make the case that animals may not be able to represent future representations *as future representations* – the overarching capacity for metaforesight that allows humans to reflect on their own natural foresight limits and act to compensate for them. Metaforesight is thus a potentially distinguishing aspect of human prospection (see also Redshaw, 2014).

For example, consider the context of strategic compensation. Bumblebees are known to use scent-marks laid down during foraging as cues about the absence of reward in flowers they or conspecifics have already visited (Pearce, Giuggioli, & Rands, 2017). However, numerous lines of evidence suggest that bumblebees are inadvertently depositing the scent-marks as footprints wherever they walk and then using them as cues later, and thus not placing the scents as intentional signals to their future self or their nestmates (e.g. Wilms & Eltz, 2008). Similarly, ants collaborate to create complex pheromone trails to store and share information about food sources and for other purposes, though these “external memories” are the product of an increasingly well-understood emergent computational system (Czaczkes, Grüter, & Ratnieks, 2015) – and one that does not rely on any individual ant representing future cognitive failures. Future studies with the great apes may shed light on the fundamentals involved in compensating for anticipated cognitive weaknesses. For instance, could chimpanzees learn to use pointing behaviours, or even markers like the ones used by the children in chapter eight, to help them remember the location of hidden food rewards? And if so, would they set these reminders selectively depending on the demands of the task?

**Table 9.1**. Animal foresight capacities and potential limits across domains. Reproduced from Redshaw & Bulley (2018).

| Future thinking domain | Capacities | Potential limits |
|---|---|---|
| Navigation and route planning | • Neural simulation of familiar and novel routes through known environments and subsequent pursuit of the same routes[r] | • May involve temporally detached mental imagery, rather than active planning |
| | • Strategic nesting and calling behaviors that increase future foraging and reproductive success in distant locations[p] | • Ecological evidence only; behavior may be based on innate predispositions and/or associative learning |
| Delayed gratification and temporal discounting | • Selecting a larger, delayed reward over a smaller but immediate one[g]; waiting for food to accumulate before eating[p]; retaining a small food reward without eating before exchanging it for a larger reward[p] | • May be limited to very short periods of time and may be based on learned associations between options and outcomes |
| Preparing for future threats | • Anxious affect produces hypervigilance and other physiological responses to prepare for potential threats[g] | • May be limited to instances in which immediately perceptible cues of threat are available and may require learned associations between the cue and negative outcomes (and/or innate predispositions to fear the cue) |
| Selecting and constructing tools to solve future problems | • Selecting an appropriate tool that can solve a nonvisible future problem and using it when the opportunity arises[c,p] | • May require past experience using an identical or similar tool successfully on the same problem, and thus tool selection may be based on rigid memory traces of past tool use rather than flexible future representations |
| | • Making an appropriate tool to solve a future problem and using it when the opportunity arises[p] | • May require the future problem to be visible and may struggle to make multiple tools when multiple future problems can be solved |
| Collecting tokens and exchanging them for future rewards | • Selecting a token and returning it for a reward after a delay[c,p] | • May be based on the past utility of the token rather than its ability to be used in a specific future exchange context, given that no preference is observed when distractor items also have past utility |
| Acting for future desire states (Bischof-Köhler hypothesis) | • Acting in a manner consistent with a future desire state[c, p] | • May require the future desire state to be triggered (i.e., experienced in the present) by pre-learned associations with the behavioral context and may not apply to interoceptive desire states that arise more directly from the peripheral nervous system |

*Note*. Each point in the “Capacities” column corresponds to one point in the “Potential limits” column. Superscripts indicate the taxa that the evidence applies to: p = primates, r = rodents, c = corvids, g = animals in general

One motivation for using comparative approaches to explore prospection is that it can provide some clues about the evolutionary phylogeny of the relevant traits. For example, by finding the various related species that possess a capacity, a phylogenetic reconstruction can allow for inferences about the last common ancestor in which that trait may have first evolved (Butler & Suddendorf, 2014). However, it is still mysterious what drove the evolution of human prospection; and, while a notoriously difficult question to unpick, it remains a critical direction for further research. I hope it is clear from this thesis that prospective cognition has myriad functions. Indeed, as discussed in chapter four, I suspect it may have been one of the key cognitive ingredients that allowed our ancestors to rapidly colonize the entire planet in the course of less than 100 thousand years after leaving Africa (Galway-Witham & Stringer, 2018), and in the process enter into a wide range of extreme and dangerous environments mainly otherwise occupied by narrowly evolved specialist species (Roberts & Stewart, 2018; Suddendorf et al., 2018). Consider for example the extraordinary foresight it would have required for humans to successfully inhabit the desolate Siberian Arctic at the apex of our planet's Last Glacial Maximum (Pitulko, Pavlova, & Nikolskiy, 2015). Warm clothes, well-provisioned fires, reliable stone and bone hunting technologies – the list of necessities to be arranged in advance was extensive. It would not have been possible to survive in many of the hostile environments that humans settled tens of thousands of years ago without comprehensive preparation for a multitude of dangerous contingencies.

A major benefit of knowing where our foresight came from and how it works is to help leverage it moving forward. There can be little doubt that the power of human foresight has played a key role in unlocking the planet for us, but in turn it has also helped to create many of the worst risks we must now manage. Some of these risks are existential in nature, such as anthropogenic climate change, nuclear war, and perhaps general artificial intelligence (Bostrom, 2013), all of which are the product of ambitious goal-directed collaboration; people collectively foreseeing and shaping the future to their design (see Shrikanth, Szpunar, & Szpunar, 2018). Now facing these threats requires a long view of the future – one that not only extends a few days, months, or years, but also transcends any individual's own lifespan. In the face of such global challenges, humans have begun to collaboratively harness foresight to a degree unparalleled in history. Seed banks such as the *Global Seed Vault* at the Norwegian island of Svalbard near the North Pole epitomize this extended prospection (Fowler, 2008; Qvenild, 2008; Westengen, Jeppson, & Guarino, 2013). Created to store the genetic material of agricultural crops in the event of catastrophe, the Global Seed Vault represents the core functions of prospection outlined in this thesis. It is the result of people anticipating potential threats and deciding to invest heavily in the present to prevent various possible calamities. Costing nearly USD$9 million to create, the vault is built on such high ground that even if the polar ice caps melt it will still be above water, preserving the crucial agricultural seeds of humanity for hundreds of years to come (Fowler, 2008). Perhaps its creators had heard the old saying: “A society grows great when old men plant trees whose shade they know they shall never sit in”.

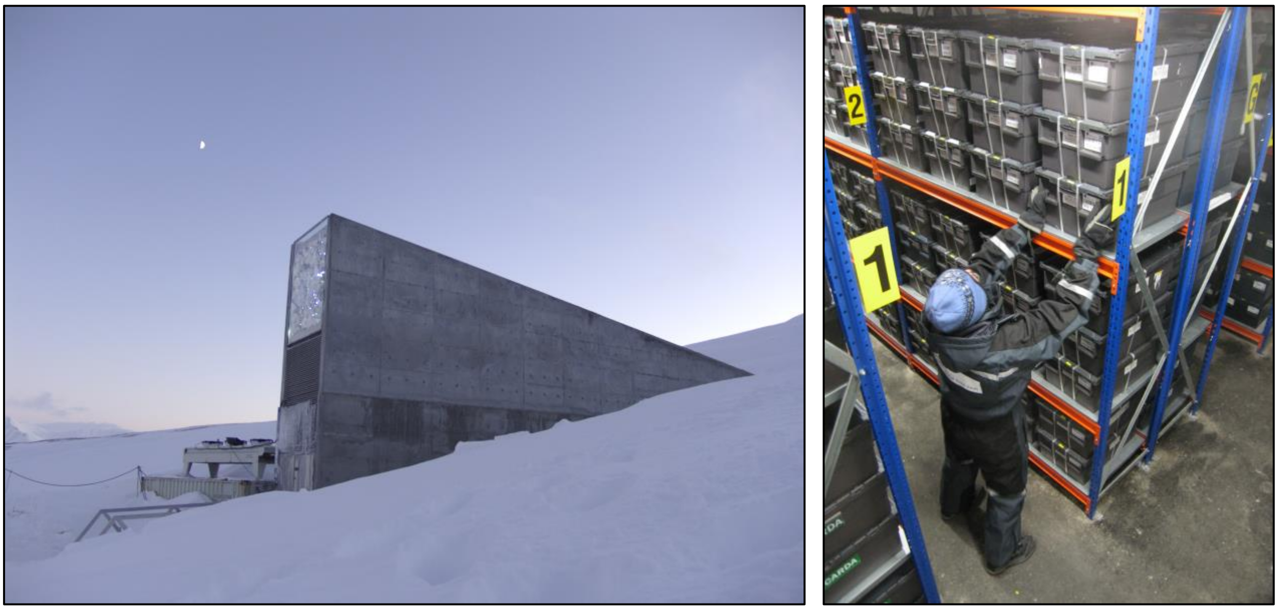


*Figure 9.1.* The Svalbard Global Seed Vault. Foresight and collaboration enable humans to make massive collective intertemporal trade-offs, prioritising future outcomes like the survival of our species at the expense of present wealth and effort. Left image by Mari Tefre, CC BY-ND 2.0. Right image by Dag Terje Filip Endresen, public domain.

### 9.6. Conclusion

Humans, more than any other species, are aware that their choices have delayed consequences and that these consequences can be changed, abated, or avoided by making different decisions in the present. As a result, we face troubling intertemporal compromises and deep anxieties. These are costs born of a highly adaptive system of prospective cognition that has evolved over millions of years to enable and motivate people to flexibly modify their decision-making in line with delayed consequences. In this thesis, I have outlined the role of foresight in adjusting preferences for immediate and delayed rewards in intertemporal choice. I have demonstrated that cuing the imagination of a positive or negative future can attenuate the rate at which delayed rewards are discounted, and begun to chart the boundaries of this effect on impulsivity. I have explored routes by which threats can be represented in the mind, used to guide decision-making, and manifest in psychopathology; and I have shown how an uncertain environment can encourage the prioritisation of immediate opportunities. Finally, I have traced the early cognitive development of a fundamental rudiment of prospective cognition: compensation for anticipated limits. Reflecting upon and compensating for natural limitations in prospective cognition, which I propose should be called metaforesight, augments the already potent adaptive functions of prospection. The capacity to modify present decision-making with the future in mind has unlocked a powerful degree of flexibility in our species that has been, and continues to be, a prime mover in our success.

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# Appendix 1. Ethics approvals

**Appendix 1.A.** Ethics approval for chapter three

THE UNIVERSITY OF QUEENSLAND

**Institutional Human Research Ethics Approval**

| | |
|---|---|
| **Project Title:** | Episodic Future Thinking and Impulsivity in Light and Heavy Drinkers |
| **Chief Investigator:** | Mr Adam Bulley |
| **Supervisor:** | Dr Matthew Gullo |
| **Co-Investigator(s):** | None |
| **School(s):** | Centre for Youth Substance Abuse Research |
| **Approval Number:** | 2014001717 |
| **Granting Agency/Degree:** | None |
| **Duration:** | 31st January 2016 |

**Comments/Conditions:**

Note: if this approval is for amendments to an already approved protocol for which a UQ Clinical Trials Protection/Insurance Form was originally submitted, then the researchers must directly notify the UQ Insurance Office of any changes to that Form and Participant Information Sheets & Consent Forms as a result of the amendments, before action.

**Name of responsible Committee:**
**Behavioural & Social Sciences Ethical Review Committee**
This project complies with the provisions contained in the *National Statement on Ethical Conduct in Human Research* and complies with the regulations governing experimentation on humans.

**Name of Ethics Committee representative:**
**Associate Professor John McLean**
**Chairperson**
**Behavioural & Social Sciences Ethical Review Committee**

Signature ______________ Date 28/1/2015

**Appendix 1.B.** Ethics approval for chapter six

16/10/2018 Mail – adam.bulley@uqconnect.edu.au

Fw: Ethics application: "Look before you leap: Episodic foresight and risk-taking behaviours"

Mr Adam Bulley

Tue 16/10/2018 14:56

To: Mr Adam Bulley <adam.bulley@uqconnect.edu.au>;

Dear Adam,

I have now had the opportunity read and review your ethics application titled "Look before you leap: Episodic foresight and risk-taking behaviours"

Based on the information you have given me, I am happy to give the study ethics clearance. Your research will have the clearance number **16-PHD-23-AH**

I hope that your project goes well and look forward to hearing about your findings in due course.

Regards and best wishes
Alex Haslam

Alex Haslam
School of Psychology
University of Queensland

Contact

@alexanderhaslam

**Appendix 1.C.** Ethics approval for chapter eight

THE UNIVERSITY OF QUEENSLAND

**Sub-Committee Human Research Ethics Approval**

| | |
|---|---|
| **Project Title:** | The development of strategic reminder setting |
| **Chief Investigator:** | Prof Thomas Suddendorf |
| **Supervisor:** | None |
| **Co-Investigator(s):** | Dr Jonathan Redshaw, Mr Adam Bulley, Dr Sam Gilbert |
| **School(s):** | School of Psychology, The University of Queensland |
| **Approval Number:** | 2018000401 |
| **Granting Agency/Degree:** | None |
| **Duration:** | 1st October 2018 |

**Comments/Conditions:**

- HREA Form, 27/02/2018
- Participant Information Sheet, 27/02/2018
- Consent Form, 27/02/2018
- Project Description, 27/02/2018

Note: if this approval is for amendments to an already approved protocol for which a UQ Clinical Trials Protection/Insurance Form was originally submitted, then the researchers must directly notify the UQ Insurance Office of any changes to that Form and Participant Information Sheets & Consent Forms as a result of the amendments, before action.

**Name of responsible Sub-Committee:**
**University of Queensland Health and Behavioural Sciences, Low & Negligible Risk Ethics Sub-Committee**
This project complies with the provisions contained in the *National Statement on Ethical Conduct in Human Research* and complies with the regulations governing experimentation on humans.

**Name of Ethics Sub-Committee representative:**
**Professor Jolanda Jetten**
**Chairperson**
**University of Queensland Health and Behavioural Sciences, Low & Negligible Risk Ethics Sub-Committee**

Signature ______________________ Date **20/03/2018**