INVESTIGATING THE RELATIONSHIP BETWEEN DELAY AND PROBABILITY DISCOUNTING: EVIDENCE FROM HEALTHY AGING AND FOCAL LESION PATIENTS

JENKIN NGO YIN MOK

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Abstract

Each day, we engage in complex decisions that involve weighing different reward outcomes by considering the prolonged impact (delay discounting) or risk (probability discounting) associated with our choices. Surprisingly, the nature of the relationship between delay and probability discounting remains unclear despite their interdisciplinary relevance to trait impulsivity and future-oriented thinking. The current dissertation aims to understand whether a common mechanism underlies delay and probability discounting through a neurocognitive lens. In Study 1, I examined the neural substrates affecting delay and probability discounting by assessing both decision-making tasks in individuals with vmPFC or MTL damage and in matched controls. Overall, only vmPFC patients discounted delayed rewards more steeply, but discounted probabilistic rewards more shallowly, than controls, representing a significant negative correlation in performance between the two discounting tasks. In Study 2, the relationship between delay and probability discounting was evaluated by determining if personal event cues, which are known to modulate delay discounting, also modulate probability discounting. Similar to previous studies, event cues led to shallower discounting of delayed rewards; however, this effect was significantly less pronounced in older adults compared to young adults. In contrast, event cues had little to no effect on the discounting of probabilistic rewards for both age groups. Study 3 extended the findings from the first two studies by examining whether personal event cues modulate probability discounting in vmPFC patients, who were recently shown to reduce delay discounting when presented with event cues. When presented with cues, vmPFC patients discounted probabilistic rewards more steeply than controls. Importantly, their rates of discounting with cues were aligned with the typical discounting observed in controls without cues, suggesting a modulatory effect that also reduced

their risk-taking. MTL patients, like controls, showed no differences in probability discounting with and without cues. Collectively, my dissertation provides evidence against the theory that a unitary trait of discounting underlies delay and probability discounting. Nevertheless, at a neurocognitive level, this set of studies shows that the vmPFC is central to reward discounting, and within its contributions to reward valuation and episodic future thinking, may instantiate self-schematic representations to modulate delay and probability discounting.

Dedication

I dedicate my dissertation to the vmPFC and MTL patients that I had the privilege of learning from. The knowledge that we gain from their experiences has brought us much closer to understanding the complexities of the human brain.

I also dedicate my dissertation to the late Dr. Donald Stuss. Though I never had the privilege of meeting him in person, his dedication to his research lives on in his academic teaching, institutional and clinical practices, and in Shayna, one of his trainees, who I have had the honour of learning from throughout my graduate studies. The small contribution that I have made to our understanding of the vmPFC's role in reward discounting would not be possible without Dr. Stuss's pioneering work on the frontal lobes.

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"Imagining the future is a kind of nostalgia." – John Green, *Looking for Alaska*

In 2015, when I embarked on my graduate degree journey, I pictured the day that I would be able to successfully complete my PhD. Six years later, here I am putting the finishing touches on my dissertation by writing this acknowledgement section and fondly looking back at the time that has passed since those early days.

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CHAPTER 1

General Introduction

Decisions interface with almost every aspect of human life, including the challenge of choosing between two outcomes that occur at different points in time or picking one of two items that have different risks and reward amount. The choices made are often based on proximity and value (Rangel et al., 2008). For example, when we are given the option to choose between items that differ in monetary or tangible value, we may opt for the option that provides the larger gain. We also tend to prefer immediate gains compared to future rewards, especially as the time it takes to obtain the future reward increases (known as delay discounting). Likewise, we devalue uncertain rewards over those that are guaranteed, especially as the probability of receiving the uncertain reward decreases (known as probability discounting). Probability discounting shares important properties with delay discounting: both are described by a similar, hyperboloid mathematical function (Green & Myerson, 2004) and have some overlapping patterns of neural activation in areas of the brain involving reward processing and evaluation of future experiences. Delay and probability discounting also share similar theoretical constructs. For example, while people often discount distant futures, it is common for people to show risk aversion in order to avoid future feelings of regret that may follow a lost gamble (see Loewenstein et al., 2001). Notably, however, delay and probability discounting are differentially sensitive to variation in both the amount (Białaszek et al., 2019; Green et al., 1999) and type of rewards that are selected (Estle et al., 2007, 2019; see Odum et al., 2020 for a review). Green & Myerson (2013) and others (Malesza & Ostaszewski, 2020; Mejía-Cruz et al., 2016) have argued that evidence based on these tasks does not support the idea of a unitary 'impulsiveness' trait. The two tasks typically have a weak, positive relationship and show opposite *magnitude* effects of discounting: smaller

delayed gains are discounted more steeply than larger delayed gains, whereas smaller probabilistic gains are discounted less steeply than larger probabilistic gains (Green & Myerson, 2004) (see Figure 1.1). Thus, it remains to be determined in the field of decision neuroscience whether delay and probability discounting are based on common processes or represent separable features of an integrated decision-making system, and whether these decisions are weighed by factors such as the age of the person making such choices and/or the presence of other variables, such as the utility of the reward and how individuals think about the future. These overarching questions guide the basis of my dissertation.

Behavioural bases of reward discounting: Are delayed and probable rewards measuring the same construct?

Our daily lives consist of a multitude of conscious and unconscious decisions. For example, do I treat myself to a delicious drink at Starbucks now or work on saving more money for a trip to Japan next year? Intertemporal choice describes the process by which people make decisions such as these that result in consequences spanning multiple time periods; in other words, how much one values an option at one point in time can influence the possibilities and availabilities of other options at an alternative point in time. In research settings, intertemporal choice has been assessed with delay discounting procedures where individuals make dichotomous choices between a smaller, immediate reward and a larger, later reward across multiple time points (e.g., receiving $50 now or $100 in three months; Rachlin et al., 1991). These procedures typically involve an iterative adjusting-amount process where the amount of the immediate reward varies across subsequent trials to converge on an estimated subjective value for each individual at a given time point (Green & Myerson, 2013). These subjective reward values reflect the tendency for the individual to subjectively weigh and favour receiving the larger, delayed reward amount or the now adjusted smaller, immediate reward choice equally

(Rachlin, 2006; Rachlin et al., 1991).[1] Results from these tasks describe a principle of behavioural economics where choices reflect the devaluation of an outcome because it is delayed or because the immediate amount is lower than the future amount. Consequently, across both human and animal species, discounting functions of these subjective values at multiple time points consistently show a relationship between the subjective value of a reward and the delay until its receipt (Calvert et al., 2011; Mazur & Biondi, 2011). Rather than a linear decline, the values of a delayed reward results in more rapid declines across shorter delays and more gradual declines across the longer delays (Figure 1.1).

In everyday life, we are also often tasked with making decisions that incur a potential risk trade-off. For example, do I wake up as soon as my alarm rings in the morning to avoid arriving late for class or do I hit the snooze button and sleep longer but run the risk of being late? Like delay discounting, these scenarios can also be manipulated in laboratory experiments. During the completion of probability discounting tasks, participants are asked to make dichotomous choices between smaller, certain rewards and larger, uncertain rewards (e.g., receiving $125 for sure or having a 20% chance at $250; Rachlin, 2006; Rachlin et al., 1991). When the probability of receiving a reward is converted into the odds against receiving the reward, a non-linear relationship similar to that obtained with delayed rewards emerges between the odds against function and the subjective value of a reward. That is, subjective valuation of a reward appears to decline more rapidly when faced with a more probable choice (i.e., lower odds against) and a

[1] The studies I will be discussing in this dissertation uses the iterative adjusting-amount procedure. While a number of other procedures have been developed for assessing both delay and probability discounting, all of them share a goal of rapidly converging on the reward value in which the individual *indifferently* prefers either dichotomous responses across different delays or probabilities. All procedural variations, including the adjusting-amount procedure, have been shown to decrease the function of delay and the odds against the outcome (probability) in a systematic fashion (McKerchar & Renda, 2012).

more gradual decline when faced with lower probabilities of receipt (i.e., higher odds against). Collectively, both delay and probability discounting are best described by a hyperboloid function (see Green et al., 2014). Plotting the relationship between subjective reward value and the length of delay until, or probability of, the occurrence of the larger outcome affirms that there may at least be a similar discounting function that explains both types of reward discounting (Figure 1.1).

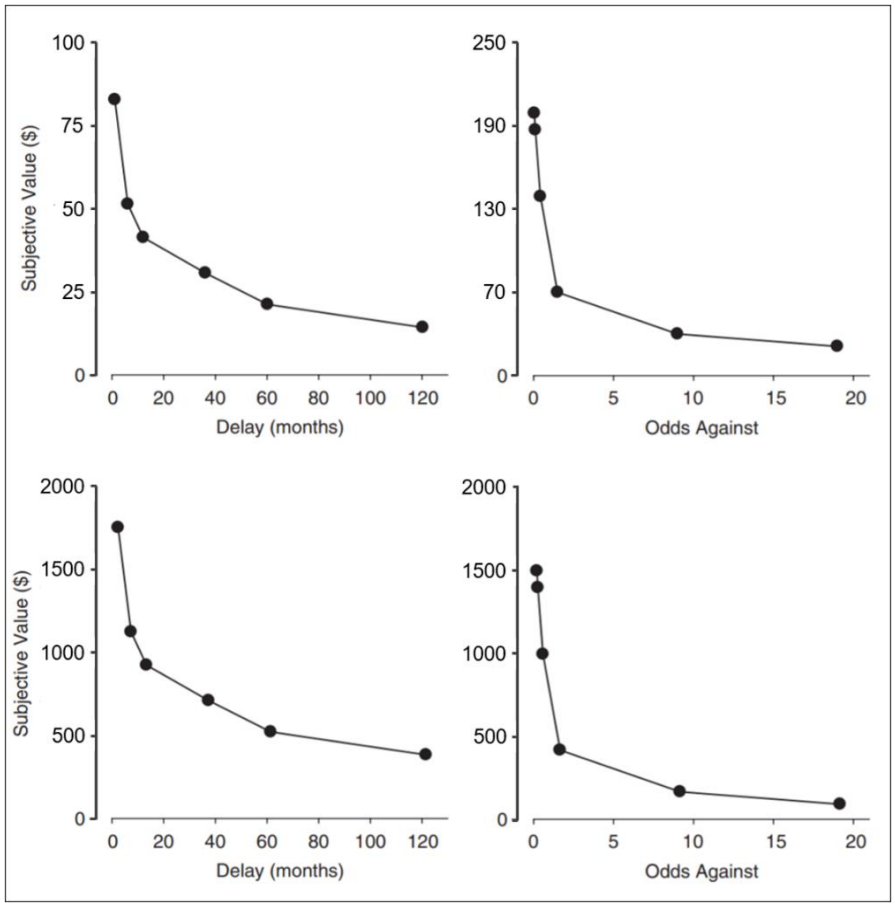

Figure 1.1. Examples of subjective value of monetary rewards plotted as a function of the time until its receipt (left panels) and the odds against its receipt (right panels). Top panels provide an example of discounting curves for smaller monetary rewards.

This commonality between delay and probability discounting, at least observed in discounting functions, has frequently raised the question of whether both forms of reward discounting measure a theoretically similar construct (Green & Myerson, 2004). One possibility is that both types of reward discounting reflect impulsivity. After all, someone who is impulsive would likely be more prone to immediate gratification in lieu of having the self-control to wait for better options. Likewise, impulsivity is also suggestive of a preference for gambling on options that can be more optimal but bring an inherent risk (Myerson et al., 2003; Yi et al., 2010). Putting it into the context of reward discounting, this makes it reasonable to predict that if there is a common construct shared between delay and probability discounting, we may expect to see someone who high in impulsivity to engage in steep delay discounting (i.e., tendency to opt for smaller, sooner rewards over larger, later options) and shallow probability discounting (i.e., tendency to choose larger, riskier rewards over smaller, guaranteed outcomes) (See Figure 1.2). Discounting of one outcome should be able to predict the degree to which another outcome will be discounted within the same individuals. Doing so would be consistent with the proposition that a similar or same trait governs both delay and probability discounting.

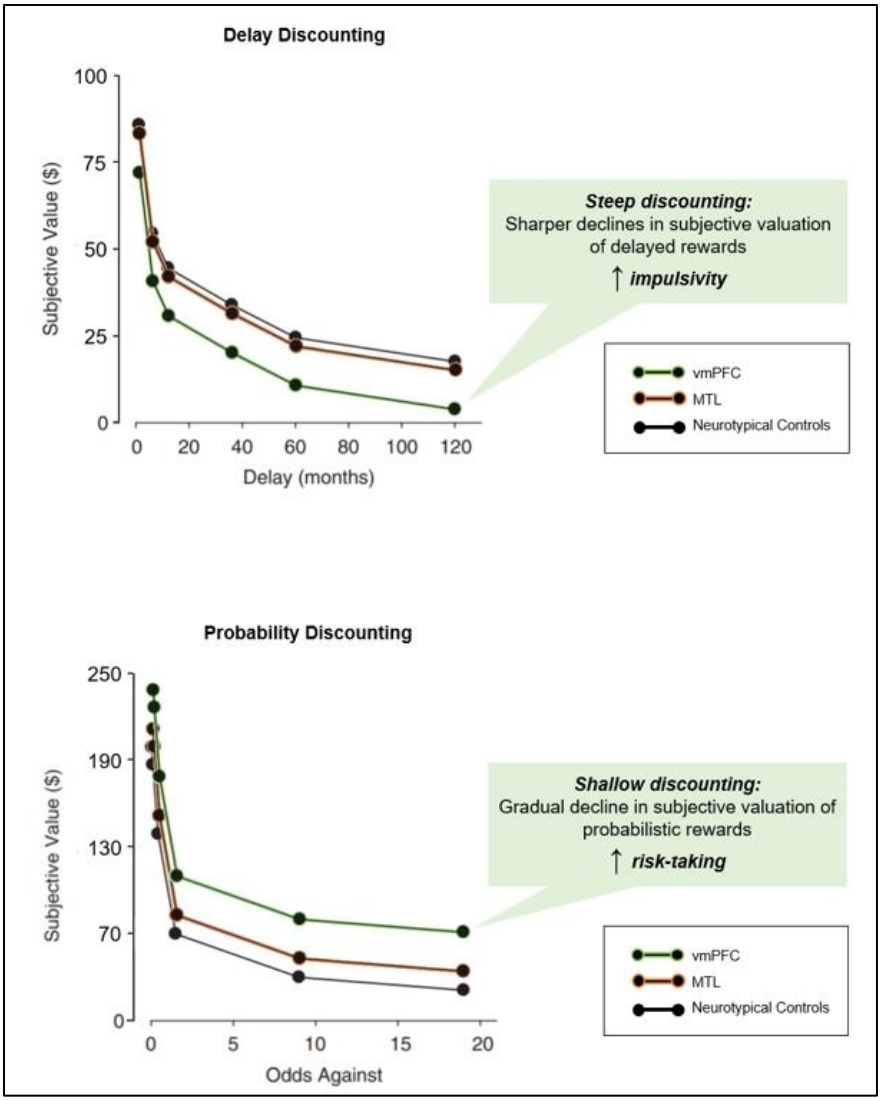

Figure 1.2. Depiction of typical delay and probability discounting response behaviours for neurotypical Controls, vmPFC patients, and MTL patients. A sharp decline in subjective valuation of rewards across the discounting curve (compared to Controls as a baseline) describes an increased selection preference for smaller immediate rewards (delay discounting; increase in impulsivity) and smaller guaranteed rewards (probability discounting; decrease in risk-taking). In contrast, a gradual decline in subjective valuation of rewards across the discounting curve describes an increased selection preference for larger delayed rewards (delay discounting;

decrease in impulsivity) and larger probabilistic regards (probability discounting; increase in risk-taking).

Nonetheless, theory does not always hold in practice and evidence accumulated in the literature points to differences between the processes underlying delay discounting and probability discounting. One of the more well-established findings in the discounting literature is the effect that reward amount has on reward discounting. In delay discounting, rewards with larger values are discounted less steeply than smaller rewards. On the other hand, this magnitude effect has a reverse effect on the degree of probability discounting, with smaller, probabilistic rewards discounted at a lower rate than larger, probabilistic rewards (Estle et al., 2007). These opposing effects hold even when considering extremes of monetary reward values ranging from $20 to $10 million (Green et al., 2013; Myerson et al., 2011). Certain manipulations also appear to affect the rate of delay more, such as the use of alternative, nonmonetary rewards (Estle et al., 2007; Odum, 2011; Paglieri et al., 2014). By contrast, probability discounting appears to be more resistant to such manipulations, though this may also reflect the far fewer studies investigating the behavioural nature of this task. Finally, if delay and probability discounting represented a unitary trait, we would predict the negative correlation between risk-taking and instant gratification as described above. Numerous studies, however, have consistently reported that the actual correlation is not statistically significant and may even be weakly positive (Myerson et al., 2003; Ohmura et al., 2006). While some theoretical constructs argue for common processes that are involved in both delay and probability discounting, these differential effects suggest that there may at least be some unique processes observed at the behavioural level that distinguish the underlying choices obtained from delayed and probabilistic rewards (Green & Myerson, 2013).

the presence of similarities and/or differences between the two forms of discounting may be further elucidated by assessing brain-behaviour relations.

Neural bases underlying reward discounting: How does brain region functionality affect delay and probability discounting?

An influential theory of decision-making purports that there are at least two basic processing stages: 1) choice valuation, which determines the subjective values of the presenting options that we then evaluate, and 2) choice selection, which comprises the weighing of the options to make the decision (Kable & Glimcher, 2007; 2009). In other words, every time we make a decision, we are actually weighing the various factors that make up the options or choices that we have available, with the choice that we make being the one that we deem to be highest in subjective value. Over the last two decades, research combining behavioural economics and cognitive neuroscience has revealed different networks of subcortical and cortical brain regions that are involved in the process of reward valuation and stimulus-response learning in guiding choices (Luhmann, 2009). In humans, the orbitofrontal/ventromedial prefrontal cortex (vmPFC), as well as neighbouring regions typically associated with the dopamine reward system (i.e., ventral striatum, posterior cingulate cortex), are notably involved in the subjective valuation of available rewards (Kable & Glimcher, 2007; McClure et al., 2004; Peters & Büchel, 2010). These regions, which make up core decision networks have been shown to activate during both intertemporal and risky choices in healthy young adults, leading to the view that the vmPFC and ventral striatum could be involved in domain-general coding of rewards, irrespective of reward choices (Peters & Büchel, 2009, 2011). Indeed, patients with lesions to the vmPFC provide additional evidence to support the vmPFC's role in reward valuation. vmPFC patients are observed to be steep discounters, opting for smaller, immediate rewards over larger, delayed rewards in delay discounting compared to healthy controls and other brain-damaged patient

populations (Peters & D'Esposito, 2016; Sellitto et al., 2010; but see Fellows & Farah, 2007). Few studies have looked at the status of probability discounting in vmPFC patients, and results from these limited studies have been mixed. One study did not find differences between vmPFC patients and controls who responded to sure and fixed risky gambles of both gains and losses (Pujara et al., 2015). A more recent study, however, found that vmPFC patients show a propensity to discount probabilistic rewards more shallowly compared to controls, in line with the theory that this population exhibits increased risk-taking and impulsivity (Peters & D'Esposito, 2020).

The vmPFC and related brain regions produce a common "neural currency" reward system also share extensive connections with the medial temporal lobes (MTL). The MTL/hippocampus has long been characterized as an important contributor to the formation of episodic memory (Tulving, 2002). Extensive bilateral damage to the MTL results in impaired vivid and detailed recollection of autobiographical memories, leaving such individuals with an inability to re-experience past personal events (Rosenbaum et al., 2008, 2009), as well as future experiences (Kurczek et al., 2015; Race et al., 2011). Several studies that highlight the role of the MTL in reward discounting have come from the animal literature. Hippocampal lesions in rodents consistently result in impaired delay and probability discounting, though the reason for this finding is debated. In rats, the hippocampus is activated during maze exploration at different decision points as the animal evaluates potential paths forward (Johnson & Redish, 2007; van der Meer et al., 2010). Previous animal studies have shown that the hippocampus is activated during maze exploration at different decision points as rats evaluate potential paths forward through its environment. Hippocampal neurons seem to fire more robustly during trials that include some form of reward, providing preliminary support for the idea that the hippocampus makes a more

direct contribution to the valuation process during decision-making in nonhumans (Johnson & Redish, 2007; van der Meer et al., 2010). In a review of the contributions of the hippocampus to human decision-making, Palombo et al. (2015a) argue that the hippocampus may also be involved in flexible learning mechanisms that helps to update previously learned value representations, retrieve learned information so that values could be generalized across related experiences, and construct novel representations that are based on the accumulation of information extrapolated from previous experiences. All of these functions have in common the involvement of the MTL/hippocampus in mediating episodic memory in the service of future choices. Thus, it is possible that the memory processes mediated by the MTL/hippocampus may be serving as an information source that can be used to determine the values of experiences that shape decisions, including those that are future-oriented.

Episodic simulation and its contribution to reward discounting in healthy adulthood

Tulving (1985) introduced the concept of *autonoetic consciousness*, which describe the human ability to "both mentally represent and become aware of subjective experiences in the past, present, and future" (Wheeler et al., 1997, p. 331). The concept of mental time travel into the remote past and the distant future lays the theoretical groundwork for the proposal that episodic future thinking is related to, and relies on, an intact episodic memory system that allows us to recollect autobiographical experiences (Schacter et al., 2012). The parallels between episodic memory and episodic future imagining forms the basis of the *constructive episodic simulation hypothesis* proposed by Schacter and Addis (2007). These researchers postulate that imagined future or fictitious episodes rely on our episodic memory to retrieve stored episodic details that can be recombined during a constructive phase to simulate hypothetical mental episodes. Support for this hypothesis comes from neuroimaging studies that show a similar

pattern of brain activation during the retrieval of episodic memories and the simulation of future or fictitious events. The overlapping network of brain regions, which includes the vmPFC and MTL as well as the posterior cingulate cortex/retrosplenial cortex, and lateral temporal and parietal regions, show increased activity when participants are asked to recall past events and image future experiences (Addis, 2020; Benoit & Schacter, 2015; Campbell et al., 2018; Stawarczyk & D'Argembeau, 2015).

Our human capacity to vividly imagine hypothetical episodes that may occur in either the distant past or future provides opportunities to guide other aspects of cognitive functioning that allows us to pursue day-to-day goals and activities (Schacter et al., 2015). Boyer (2008) suggest that the ability to mentally orient to the future has evolutionary value, as it may serve as a motivational force that constrains our impulsive, in-the-moment behaviours or counteracts our tendency to be biased towards immediately gratifying options and rewards (Baumeister et al., 2011; Benoit et al., 2018; Bulley et al., 2016). In intertemporal choice, the ability to make future-oriented decisions is likely related to how we think about the future during delay discounting tasks (Peters & Büchel, 2010). Similarly, decisions regarding probabilistic rewards could also involve some form of episodic future imagining, by way of anticipating the regret that would follow the failure to receive a reward (e.g., Loomes, Graham & Sugden, 1982; but see Craver et al., 2014). Most work on the contributions of episodic future thinking to reward discounting has considered the extent to which discounting of future rewards is mitigated by the imagining of episodic cues prior to the completion of a trial on delay discounting tasks (see Benoit et al., 2018, for a review). This was observed in seminal studies by Peters and Büchel (2010) and by Benoit et al. (2011). Participants in these studies showed a modulation of discounting, with improved valuation of future reward options that led to increased preference for future-oriented choice

selections when presented with episodic cues to imagine specific future events. Importantly, this phenomenon appears to be mediated by the same network of brain regions that is involved in episodic memory and future thinking. Reduced delay discounting was correlated with increased activity within, and coordination between, the vmPFC and hippocampus/MTL in the healthy intact brains of young adult participants (Peters & Büchel, 2010).

While this modulatory effect observed in healthy young adults is quite robust, questions remain as to whether the same effects apply to populations that may have a reduced capacity for episodic future thinking due to lesions or to age-related psychophysiological changes to brain regions that are implicated in episodic future thinking. With respect to the latter, as our capacity to remember past events and imagine future episodes typically declines with age (Gaesser et al., 2011; Lapp & Spaniol, 2017), it may be expected that similar decline would be observed on tests of delay and probability discounting given the future-oriented component that may be associated with both tasks. Surprisingly, studies that have assessed delay discounting across the adult lifespan have been largely inconsistent, with some suggesting that older adults show a greater tolerance for temporal delays compared to young adults (Löckenhoff, 2011), and others suggesting the opposite (see Mohr et al., 2010 for a review). Previous studies that have tested older adults on delay discounting with episodic cues have observed a cueing effect similar to that found in young adults (Kwan et al., 2015; Palombo et al., 2015b); however, the older adults in these studies were used as a comparative control group for amnesic patients and not directly compared to younger adults. Studies evaluating age-related changes in probability discounting have been even more limited. Only one study has evaluated age-related changes in standard probability discounting with findings suggesting that risk-taking behaviours increased only for

nonmonetary rewards and not for monetary choices (Seaman et al., 2016). To date, studies have not evaluated the generalizability of using episodic cues to modulate probability discounting.

Episodic simulation and its contribution to reward discounting in patient-lesion models

The vmPFC and MTL have been described as playing complementary, interactive roles in supporting memory and imagination functions in forming past, future, and simulated personal experiences (Barry et al., 2019; Campbell et al., 2018; Zeithamova et al., 2012). These two brain regions appear to be involved in a constructive process whereby prior details are reinstated and/or recombined during episodic memory and imagining of future episodes (see Schacter et al., 2017 for a review). Of these two brain regions, the vmPFC is believed to be critical to both episodic foresight and value-based decision-making in humans, particularly for judging rewards (Fellows & Farah, 2007; Levy & Glimcher, 2012; Rangel & Clithero, 2012) across many kinds of tasks, including those considering risk, adaptiveness to probabilistic outcomes, as well as prosocial economic considerations (Camille et al., 2004; Henri-Bhargava et al., 2012; Pujara et al., 2015). This view is supported by patient-lesion studies demonstrating that damage to the vmPFC leads to deficits in value-based decision-making, which includes problems ranging from simple judgements to learning appropriate valuations that maximize choices and benefits (see Fellows, 2011 for a review). Tying these together, the vmPFC is frequently associated with valuation of future rewards (Kable & Glimcher, 2007), with the impaired decision-making in vmPFC patients having been described as a diminished ability to conjure imagined scenarios that allow future consequences to be anticipated following a decision (Bechara, 2005; Sellitto et al., 2010, 2011). The nature and extent of deficits in reward valuation and discounting of future rewards are unclear, however, as other studies have shown discounting of future selections and value ratings that are commensurate with those seen in demographically matched controls (e.g.,

Fellows & Farah, 2005; Vaidya & Fellows, 2015). These disparate findings could perhaps be the result of various factors that could be better addressed, including a lack of comparative patient groups, differences in location of lesion, and limits to the length of the future delay and reward amounts on the intertemporal choice tasks that were used. Similar to the vmPFC, the hippocampus/MTL system may serve a role in guiding decisions that require flexible relational representations via episodic simulation of novel and hypothetical events (Rubin et al., 2014; Shohamy & Wagner, 2008). Damage to the MTL leads to impairments in recollection of episodic memory (while generally preserving semantic knowledge), which is further expressed in the imagining of future events (McCormick et al., 2018; Nadel & Moscovitch, 1997; Tulving, 2002).

While damage to both regions separately lead to deficits in imagining future events, the nature of the impairment appears to be different in each case. The vmPFC appears to govern simulated events that are familiar or relevant to the self (Benoit et al., 2014; D'Argembeau et al., 2010) and may even contribute differentially to episodic future thinking more than episodic remembering of past events (Ciaramelli, Anelli, et al., 2021). This may explain why individuals with vmPFC lesions generate fewer details for events relating to themselves (Verfaellie et al., 2019). This lack of episodic details about the self may be unique to vmPFC patients and could relate to impairment within other cognitive processes, such as decision-making. These findings converge with other evidence suggesting that the vmPFC contributions to episodic future thinking may, in turn, reduce discounting rates of delayed rewards compared to immediate rewards in intertemporal choice tasks. This was suggested by a patient-lesion study by Sellitto et al. (2010), and later by Peters & D'Esposito (2016), which showed that damage to the vmPFC leads to an increase in impulsive choices and preference for immediate gratification across different reward types and amounts, possibly due to disruptions to imagery about future rewards

at the time of choice. Complementary evidence has emerged more recently from patient studies demonstrating the necessity of the vmPFC in goal-directed decision-making, and in neuroimaging studies showing increased prefrontal region activation while participants imagined the valuation of anticipated rewards (Benoit et al., 2011; Bray et al., 2010; Hakimi & Hare, 2015; Reber et al., 2017). This "myopic" viewpoint of the future in patients thus may be explained by the engagement of the vmPFC during the retrieval and simulation of episodic content that encompasses our ability to remember the past and imagine future, episodic experiences (Addis et al., 2009; Bellana et al., 2017; Benoit & Schacter, 2015; Buckner & Carroll, 2007). Taken together, the vmPFC seems critical to decision-making, particularly in instances when the subjective value of rewards that are not immediately available must be considered. Whether these common features requiring vmPFC integrity are applicable to other decisions involving non-temporal outcomes (e.g., making choices that involve uncertain rewards), and how they can be manipulated, will be studied and discussed in this dissertation.

Patients with MTL/hippocampal damage show another side to the relationship between episodic future thinking and economic decision-making. Unlike their vmPFC counterparts, differences seen in hippocampal patients' future-oriented decisions may coincide with episodic memory impairment. Though both patient groups show similar preferences for short-term gains on laboratory-based risk-taking and gambling tasks (Gupta et al., 2009), MTL patients show a proclivity to making more random choices that more likely reflects an inability to recognize, or *remember*, options that reduce long-term losses (Rosenbaum et al., 2016). This pattern differs from vmPFC patients' preference for impulsive, riskier choices that have a greater degree of immediacy and "certainty" (Bechara et al., 1994; Clark et al., 2008; Floden et al., 2008; Pujara et al., 2015). Similar impoverishment to foresight and envisioning future outcomes (Race et al.,

2011; Rosenbaum et al., 2009) would suggest an additional difficulty impacting future-oriented decisions (e.g., intertemporal choice and delay discounting), even when patients do not have to keep track of and/or remember their past choices. Despite impairment to episodic future thinking, however, hippocampal patients are virtually indistinguishable from healthy age- and education-matched controls in delay discounting (Kwan et al., 2012, 2013) and in probability discounting tasks in which time perspective is involved in waiting for wins during repeated gambles (Kwan et al., 2013; Rachlin et al., 1991; Vanderveldt et al., 2017).

Bridging these lines of work, Peters (2011) suggested that impaired decision-making after vmPFC damage may reflect either an inability to regard the future or difficulties assigning reward value to decisions that lead to impulsive responding. This may mean that different forms of decisions rely on an integration of the episodic memory/prospection and valuation networks to track the subjective value of rewards over time (Benoit et al., 2011; Peters & Büchel, 2010). Again, previous patient-lesion studies have shown that vmPFC patients discount future rewards more steeply than controls (Sellitto et al., 2010), whereas MTL patients are relatively indistinguishable from controls on both delay and probability discounting, even though episodic memory and future imagining are compromised in both patient groups (Kwan et al., 2015; Palombo et al., 2015b). However, contributions of episodic future thinking appear to have disparate effects on reward discounting in MTL and vmPFC patients. Unlike healthy controls and vmPFC patients, MTL patients do not demonstrate reduced delay discounting when presented with cues to imagine future personal events associated with receiving the delayed reward (Kwan et al., 2015; Palombo et al., 2015b). These discrepancies in reward discounting observed between vmPFC and MTL patients suggest that different mechanisms may be at play for each brain region when helping us to make everyday decisions about prolonged and probable

outcomes. It is possible that these tasks represent independent tendencies in healthy individuals, but the decisions involved are complex, and localized damage to one area of the brain (e.g., vmPFC) could affect both forms of discounting but in different ways. For vmPFC patients, the impairment in delay discounting may even suggest value-based mechanisms that do not solely rely on episodic future thinking, instead relying on a mechanism that interacts with or enables reward valuation of both delayed and risky rewards.

Overview of Studies in Dissertation

To this end, the objective of my dissertation is to determine the relationship between delay and probability discounting by investigating if the two are similarly affected by 1) lesions to the vmPFC vs. lesions to the MTL, brain areas involved in reward valuation and episodic future thinking; 2) cues to imagine personal future events in older adults who are known to experience changes to MTL structure and function, including less detailed episodic future imagining; and 3) cues to imagine personal future events in patients with vmPFC lesions vs. MTL lesions. Both patient-lesion and healthy aging approaches will thus allow us to investigate whether suboptimal changes to brain structures lead to impaired cognitive processes that bias our selection of delayed and/or probabilistic outcomes. If it is the case that there is a fundamental mechanism or, at the very least, a process common to both delay and probability discounting, then we should see similar effects of lesions, aging, and cueing. My dissertation will explore these considerations across three studies by answering the following questions:

1. Are delay and probability discounting dissociable in vmPFC and MTL patients?

In Study 1, I examined the contributions of the vmPFC to both delay and probability discounting to better define the neural bases of reward valuation that distinguishes this area of the brain from the MTL. Most research on the vmPFC involves laboratory-based risk-taking

measures that place demands on working memory and/or declarative memory (Mata et al., 2011). In studies of intertemporal choice that place little-to-no demand on working memory and declarative memory, vmPFC patients nevertheless show a preference for immediately available rewards (Peters & D'Esposito, 2016; Sellitto et al., 2010), suggesting a greater propensity for impulsivity and risk-taking. The increase in impulsivity leading to greater preferences for immediate rewards rather than delayed, but more optimal, rewards in delay discounting may indicate that vmPFC patients would also be bigger risk-takers, as suggested by Floden et al. (2008). However, to date, a very limited number of studies have specifically investigated probability discounting in this population. Only one other study in humans has investigated the effect of focal vmPFC lesions on delay and probability discounting in the same individuals, providing further evidence that vmPFC damage is associated with greater impulsivity and risk-taking in reward discounting. This study was conducted as a measure of reaction time on risk-taking, however, and no direct comparisons between delay and probability discounting were conducted (Peters & D'Esposito, 2020). Furthermore, this study did not compare the results of the reward discounting for the vmPFC patients to another patient group that have in common some areas of impairment. Thus, a larger MTL sample than a previous study (Kwan et al., 2013) was included to determine if, indeed, these patients are indistinguishable from controls and whether they differ from vmPFC patients. The inclusion of these MTL patients is particularly apt as these individuals also show impaired episodic future thinking but do not seem to differ from controls in either delay or probability discounting. Inclusion of patients with MTL lesions can help to establish whether delay and probability discounting jointly rely on episodic future thinking and how responses to reward discounting tasks are similar or differ following compromise to either brain region.

2. *Are probabilistic reward choices attenuated by episodic cues in healthy young and older adults?*

In Study 2, I examined the potential contributions of episodic future thinking to delay (temporal) and probabilistic (atemporal) discounting, inspired by a proposal by Boyer (2008) that imagining and constructing episodic experiences evolved to drive future-oriented goal-directed behaviours. The tendency for personally meaningful, cued experiences (e.g., imagining a personal event that is tied to the reward) to steer people towards more optimal future outcomes has been observed in diverse populations, mainly in healthy young adults (see Rung & Madden, 2018) and individuals with behavioural concerns (e.g., substance use). Previous studies have found that individuals with MTL lesions do not show the modulatory benefits of episodic cueing during delay discounting (see Kwan et al., 2015; Palombo et al., 2015b). Older adults experience changes to MTL structure and function (Bettio et al., 2017; Jobson et al., 2017), but typically have their vmPFC and related abilities intact. These changes to the MTL results in the generation of future events that are less detailed than those generated by young adults (Schacter et al., 2013). Thus, it remains to be seen whether older adults also do not benefit from episodic cueing during intertemporal choice or show a dampened response as a result of reduced MTL integrity. Furthermore, episodic future thinking has yet to be well studied in other forms of reward discounting, such as reward choices that involve probable outcomes. It is not yet known whether the benefit of episodic cueing depends on the temporal association of the cues to the imagined receipt of the delayed rewards or whether episodic cues may also benefit risk-based decisions that are not necessarily tied to a future time. If it is the latter, this may provide some evidence in support of a general cognitive process involving episodic simulation that supports reward valuation across both farsighted and risky rewards. Accordingly, Study 2 simultaneously considered two topics of interest in reward discounting: (1) Determining whether episodic event

cueing modulates probability discounting like delay discounting in healthy adults, and (2) whether age of these healthy participants modules the effects of episodic cueing on the discounting of either delayed or probabilistic rewards.

3. Are probabilistic reward choices attenuated by episodic cueing in vmPFC and MTL patients?

In Study 3, I coalesced the findings from Studies 1 and 2 by examining the contributions of the vmPFC and MTL to the discounting of risky rewards with and without episodic and personally meaningful event cues. While damage to both areas of the brain can lead to impoverished episodic memory and future thinking, there may be qualitative differences in how and why these two groups of patients are impaired. Despite responding to delay and probability discounting in a similar way to healthy controls, MTL patients generally do not benefit from episodic cues during delay discounting (Kwan et al., 2015; Palombo et al., 2015b). On the other hand, Ciaramelli, De Luca, et al. (2021) recently showed the delay discounting of vmPFC patients was modulated by cues to imagine personal future events. One possible interpretation is that the value-based contributions of the vmPFC to reward discounting may not rely solely on episodic future thinking and instead reflects instantiation of personally meaningful schematic representations to enhance subjective valuation irrespective of the types of reward discounting (i.e., delay or risk-based). If so, then both delay and probability discounting of rewards should be modulated by episodic cues in vmPFC patients, as these would serve to activate a self-schema to subjectively enhance reward value. On the other hand, individuals with MTL lesions are unlikely to benefit from the support of external event cues due to intact reward valuation systems and specific impairments to episodic simulation. These hypotheses were tested in Study 3 by presenting vmPFC and MTL patients with episodic cues as they performed a probability

discounting task and comparing their results to demographically-matched control participants who were part of the older adult sample in Study 2.

Altogether, findings from these studies add insight into the cognitive and neural substrates involving rewarding discounting. In particular, my studies seek to identify whether there is evidence supporting for a multifaceted, integrative role of the vmPFC in reward discounting, which would lend support to the notion that delay and probability discounting can be modulated by a common cognitive process chaired by the vmPFC.

CHAPTER 2

Study 1: Comparing Delay and Probability Discounting following lesions to the vmPFC and MTL

People must often make decisions involving future and/or risky outcomes that require them to choose between smaller-immediate and larger-delayed rewards or between smaller-certain and larger-probabilistic rewards. Such decisions are modeled in the laboratory using tasks that measure delay and probability discounting, where the terms *delay discounting* and *probability discounting* respectively refer to the finding that increasing the time to a future reward and/or decreasing the likelihood of a probabilistic reward decrease the reward's subjective value.

It has been proposed that a common mechanism (impulsive decision-making) underlies both delay discounting and probability discounting. After all, rewards available after longer delays are actually less certain than immediate rewards, and both types of discounting are well described by a hyperboloid function (Green & Myerson, 2004). However, previous research has shown that delay and probability discounting respond in opposite ways to manipulations of reward amount, and also reflect relatively independent traits in healthy adults, as evidenced by the finding that the tendency to discount delayed rewards is often uncorrelated with the tendency to discount probabilistic rewards (for a review, see Green & Myerson, 2013). As a result, exactly how these two types of discounting are related remains a matter of dispute.

Examining neural mechanisms of decision-making could shed light on the relation between delay and probability discounting. Functional neuroimaging experiments on delay discounting (e.g., Benoit et al., 2011; Peters & Büchel, 2010) show that the effects of episodic imagining on the value of future rewards are mediated by increased activity and coordination between the ventromedial prefrontal cortex (vmPFC) and the medial temporal lobes (MTL).

Direct support for a vmPFC role in value-based decisions comes from studies showing that lesions to the vmPFC may impact subjective valuation and weighing of key visual attributes pertinent to the process involved in reward-driven decision-making (Vaidya & Fellows, 2015; Vaidya et al., 2018). Indeed, Seaman and colleagues (2018) found that subjective valuation of different decision types – delay, probability, and effort-based discounting – share overlapping activity in the medial PFC after differences in participants' discount rates across the three tasks are taken into consideration.

Activation of the vmPFC has further been shown to occur during value comparison and when evaluating differences between outcomes (i.e., magnitude, immediate availability; Boorman et al., 2013; Hare et al., 2014) and various categories or perceptual inputs of rewards (Bartra et al., 2013; Levy & Glimcher, 2012; see Clithero & Rangel, 2014). The vmPFC/orbitofrontal cortex has been implicated in reward sensitivity and greater subjective risk-taking tendencies (Blankenstein et al., 2017; Engelmann & Tamir, 2009). In separate work, Luhmann and colleagues (2008) found that vmPFC/orbitofrontal cortex contributes to the valuation of both delayed and probabilistic reward types, suggesting that activation in this region leads to the value of both kinds of rewards being represented in a common "neural currency" and domain-general subjective valuation system (Bartra et al., 2013; Montague & Berns, 2002; Peters & Büchel, 2009; see Weber & Huettel, 2008 for a review).

Previous studies have reported that patients with lesions to the vmPFC show steeper discounting of future rewards compared to healthy and brain-damaged controls (Peters & D'Esposito, 2016; Sellitto et al., 2010; but see Fellows & Farah, 2005), consistent with the view that vmPFC is critical for reward valuation. As noted by Stuss and Levine (2002), patients with vmPFC lesions also have difficulties imagining detail-rich future events, and this may relate to

their steep delay discounting (see also Bertossi, Tesini, et al., 2016). However, patients with MTL lesions also have impaired future thinking, yet they are indistinguishable from matched controls in delay discounting (Kwan et al., 2012; 2013), at least in the absence of episodic cues (Kwan et al., 2015; Palombo et al., 2015b). This warrants further inquiry into the relation between future thinking and delay discounting in vmPFC (and MTL) patients.

For example, the future is inherently less certain than the past. Is this the reason why, on delay discounting tasks, vmPFC patients tend to choose smaller, immediate rewards available now, over larger rewards not available until later? Does this suggest that such patients bypass more deliberate consideration informed by reward utility? If this is the case, we would expect steep delay discounting in vmPFC patients to be accompanied by steep probability discounting. That is, as much as an individual with vmPFC damage will choose smaller, immediate rewards over larger, delayed ones, so, too, will these patients be expected to choose smaller, certain rewards as opposed to gambling on larger, probabilistic ones. This dual pattern has been observed in rats with lesions in homologous regions (Mobini et al., 2002).

Notably, however, vmPFC patients are not classically, nor consistently, described as risk-averse. In seminal studies using the Iowa Gambling Task, vmPFC patients were significantly more likely than controls to choose from "bad" decks that result in large, immediate gains but even larger losses overall than "good" decks (Bechara et al., 1996; 2000; Hochman et al., 2010), suggesting greater risk-taking. This pattern of results also is observed in MTL patients (Gupta et al., 2009; Gutbrod et al., 2006; Rosenbaum et al., 2016). However, performance on gambling tasks may be confounded because probabilities must be learned, placing greater demands on working memory and declarative memory (Floden et al., 2008; Mata et al., 2011), and because reward delivery and contingencies have differed markedly across studies.

A more recent study with vmPFC patients showed increased risk-taking only under "hot" decision-making conditions in which immediate reward feedback was provided after each choice, requiring the online integration of affective states with other sources of information (e.g., reward probability or magnitude), and not under "cold" conditions where feedback was provided cumulatively at the end of the task, thus minimizing integration demands and leading to more deliberate decision-making (Spaniol et al., 2019). Probability discounting tasks like the one used in the present study represent cold conditions, as no feedback is provided, and, because they are quite different from card tasks like the one used by Spaniol et al., they provide a test of the robustness of their findings.

To date, only one other study has investigated both probability discounting and delay discounting in patients with focal lesions to vmPFC (Peters & D'Esposito, 2020), and the results were consistent with shallower probability discounting and steeper delay discounting than in control participants that would suggest a common trait of impulsivity. However, a separate patient-lesion study comparing choice between sure and fixed risky gambles of gains and losses (50% certainty) that used a smaller patient group was unable to establish clear differences in risky reward choice selection between vmPFC patients and controls; a significant difference was found only when vmPFC patients were compared to a non-specific group of patient controls (Pujara et al., 2015). Thus, the present study will be one of the first to formally investigate whether vmPFC patients discount probabilistic, risky rewards more or less steeply than controls using an established iterative choice-adjusting procedure (Green & Myerson, 2004). Inclusion of MTL-lesion patients as a comparison group will further help to determine if delay and probability discounting are affected similarly when episodic future thinking is compromised (Bertossi, Aleo, et al., 2016; Bertossi, Tesini, et al., 2016).

Here we test the idea that focal lesions that affect one type of discounting necessarily affect the other type. Importantly, we test this idea at both the group level as well as at the level of the individual patient. For example, if a lesion group's discounting of probabilistic rewards is, on average, shallower than that of controls, reflecting greater risk-taking, will their discounting of delayed rewards also differ from that of controls, and if so, will it be shallower or steeper? And at the individual level, if a patient's probability discounting is shallower than average for their group, will their delay discounting be shallower as well, or will it be steeper, as would be predicted if their lesion has increased their impulsiveness? If delay and probability discounting share a component process supported by vmPFC, as we suspect, then lesions of vmPFC should affect both types of discounting. Moreover, if that process contributes to an individual's impulsiveness, then delay and probability discounting should be affected in opposite ways at both the group and the individual level. In the present study, we take a patient-lesion approach to shed light on the precise neural computation supported by vmPFC when rewards are evaluated as well as on the very nature of impulsiveness.

Methods

Participants

Focal lesion patients. All patients were recruited from Baycrest Health Sciences. Patients were in the stable phase of recovery and had no additional diagnosis that would affect cognitive abilities other than those pertaining to their brain injuries.

vmPFC. Eight individuals (4 men) with vmPFC lesions were tested, seven of whom acquired focal brain lesions following rupture of an anterior communicating artery (ACoA) aneurysm (M = 57.5, SD = 9.5). The eighth, R.L. (76 years old), was identified as having a focal vmPFC lesion following an anterior cerebral artery stroke (ACA). All patients were tested

between 2015 and 2019, at least 12 months post-lesion (range: 12-96 months). Inclusion of patients was based on the location of their lesion evident on magnetic resonance imaging (MRI) or computerized tomography (CT) scans (see Figure 2.1).

Individual vmPFC lesions were manually drawn on each slice of normalized T1-weighted template MRI scans from the Montreal Neurological Institute using MRIcro software (Rorden & Brett, 2000), based on the most recent MRI or CT scan available. This manual procedure combines segmentation (identification of lesion boundaries) and registration (to a standard template) into a single step, with no additional transformation required (Kimberg et al., 2007). Figure 2.1 shows the location, extent, and overlap of the vmPFC patients' lesions. Lesions were bilateral in 6 of the 8 cases and left-lateralized in the other two cases, largely affecting Brodmann areas (BAs) 10, 11, 32, 24, and 25. Four patients had minimal damage to lateral prefrontal cortex (BAs 9, 46, 47), constituting ~ 5% of their lesion volume, whereas their vmPFC lesions were on average 10 times larger. Patients CR and RL had damage to visual cortex (BAs 17, 18, 19, 37) that constituted ~ 41% and ~ 32% of their lesion volume, respectively. These patients did not have visual problems precluding their participation in the study. They attained normal scores on the Rey-Osterrieth Complex Figure test (percentile scores: 66 and 68; Spreen and Strauss, 1991) and on the Wechsler Test of Adult Reading (percentile scores: 55 and 47; Holdnack, 2001), and showed a good understanding of the discounting test instructions.

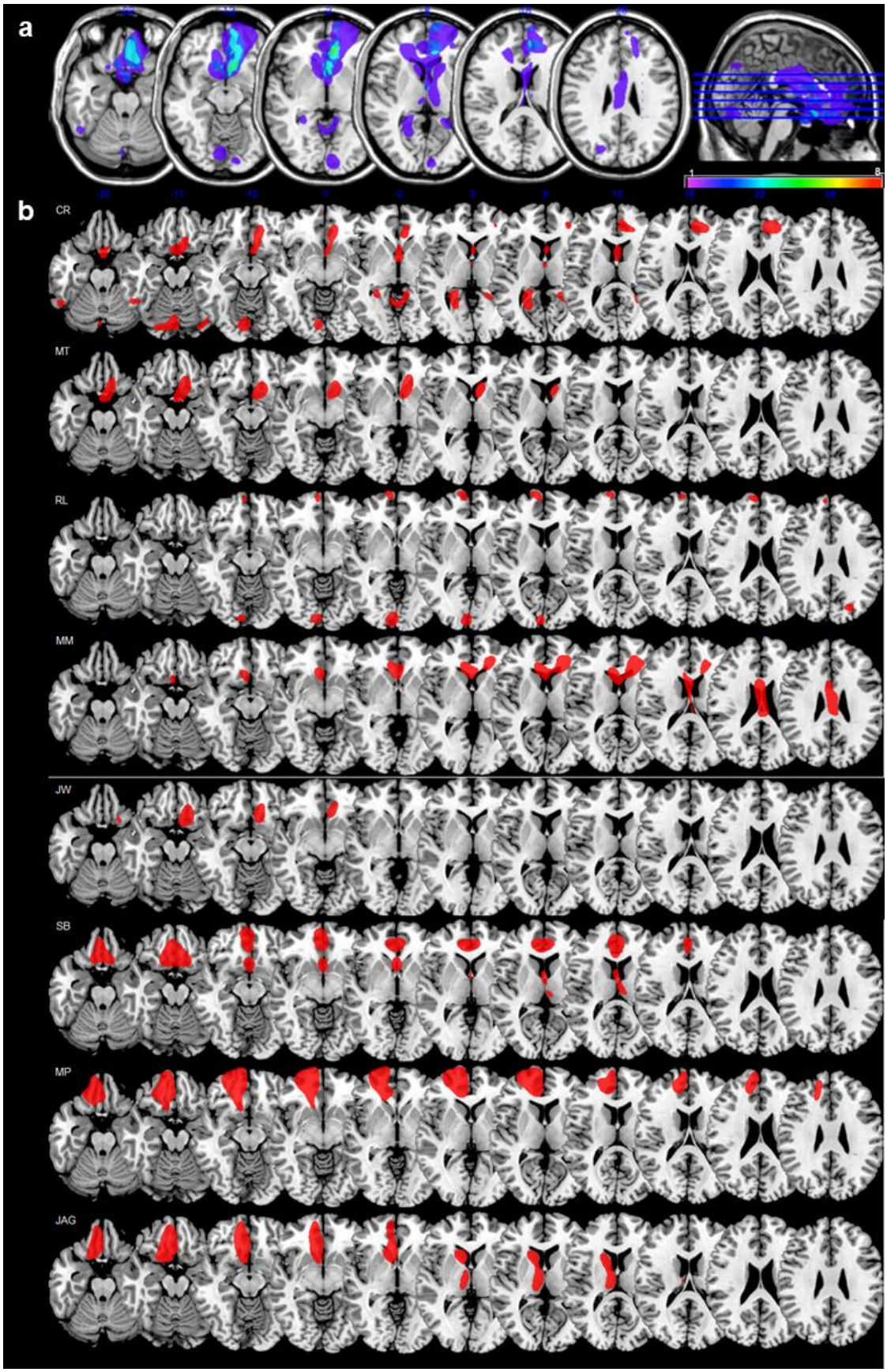
a
1
8
b
CR
MT
RL
MM
JW
SB
MP
JAG

Figure 2.1. Lesion location and extent in vmPFC patients. a) Axial slice template illustrating lesion overlap across vmPFC patients. Slices are 8mm apart at z = -30, -22, -14, -6, +2, and +10, with level of slice depicted in the sagittal reference image. The color bar indicates the number of patients with damage to a particular area, with purple representing regions damaged in only one patient and red representing regions damaged in all 8 patients. The image was created using MRIcro software (Chris Rorden; www.psychology.nottingham.ac.uk/staff/cr1/mricro.html). b) Axial slice templates illustrating the lesion location and extent for each of the vmPFC patients. Slices are 8 mm apart at z = -22, -17, -12, -7, -2, +3, +8, +13, +18, +23, +28. Neurological convention is followed (left hemisphere presented on the left). Details of lesion location and size are provided in the manuscript, and etiology, demographic information, and neuropsychological profiles are presented in Table 2.1.

MTL. Ten individuals (all men, M = 55.3, SD = 5.9) with MTL lesions also were tested. The etiology of brain damage for these cases included anoxia (n = 4), encephalitis (n = 2), stroke (n = 2), temporal lobe resection (n = 1), and traumatic brain injury (n = 1). All of the patients have been described previously (Keven et al., 2017; Kwan et al., 2013, 2015, 2016; Robin et al., 2019), with the exception of two patients (R.V., J.M.). K.C.'s and L.D.'s lesions were bilateral and included the hippocampus and surrounding MTL cortices. K.C. had widespread lesions beyond the MTL including small lesions to left and right posteromedial orbitofrontal cortex (Gao et al., 2020). D.A.'s lesions were also widespread, extending beyond the MTL bilaterally (though primarily right) and into ventral frontal, anterior cingulate, and occipital cortices. B.L. experienced bilateral lesions to his hippocampus that selectively affected the dentate gyrus and part of the CA3 subfield. He also experienced volume loss within the left superior parietal lobe and right precuneus. S.N.'s hippocampal damage was greater on the left, with additional volume

loss to left occipital lobe and basal nuclei. M.H. contracted herpes simplex encephalitis, resulting in bilateral MTL atrophy as well as damage along the right medial occipital and inferotemporal cortices (Keven et al., 2017). D.G., J.D., and J.M. suffered anoxia secondary to cardiac arrest and could not be scanned due to medical contraindications (See Figure 2.2). MTL pathology in these cases was inferred based on etiology and neuropsychological profiles (Table 2.1).

Six of the participants with MTL lesions had been previously tested on the delay discounting task, and their data were included for comparison in the present study: K.C. (Kwan et al., 2012), D.A. and D.G. (Kwan et al., 2013), L.D., B.L., and S.N. (Kwan et al., 2015). Data for three of the patients (K.C., D.A., and D.G.) who had been tested on the probability discounting task (Kwan et al., 2013) were also included for comparison. See Table 2.1 for additional demographic information and neuropsychological test performance for both patient groups.

Importantly, most of the vmPFC and MTL patients have documented deficits in episodic prospection, producing fewer internal (episodic) details than healthy controls on a Galton-Crovitz cue-word test. Results for 5 of the 10 MTL patients (D.A., D.G., L.D., S.N., and B.L.) were previously reported (Kwan et al., 2016). Results of the episodic prospection abilities of 3 additional MTL patients and 6 of 8 vmPFC patients are listed in Table 2.2, with comparisons made with the control group from Kwan et al. (2016).

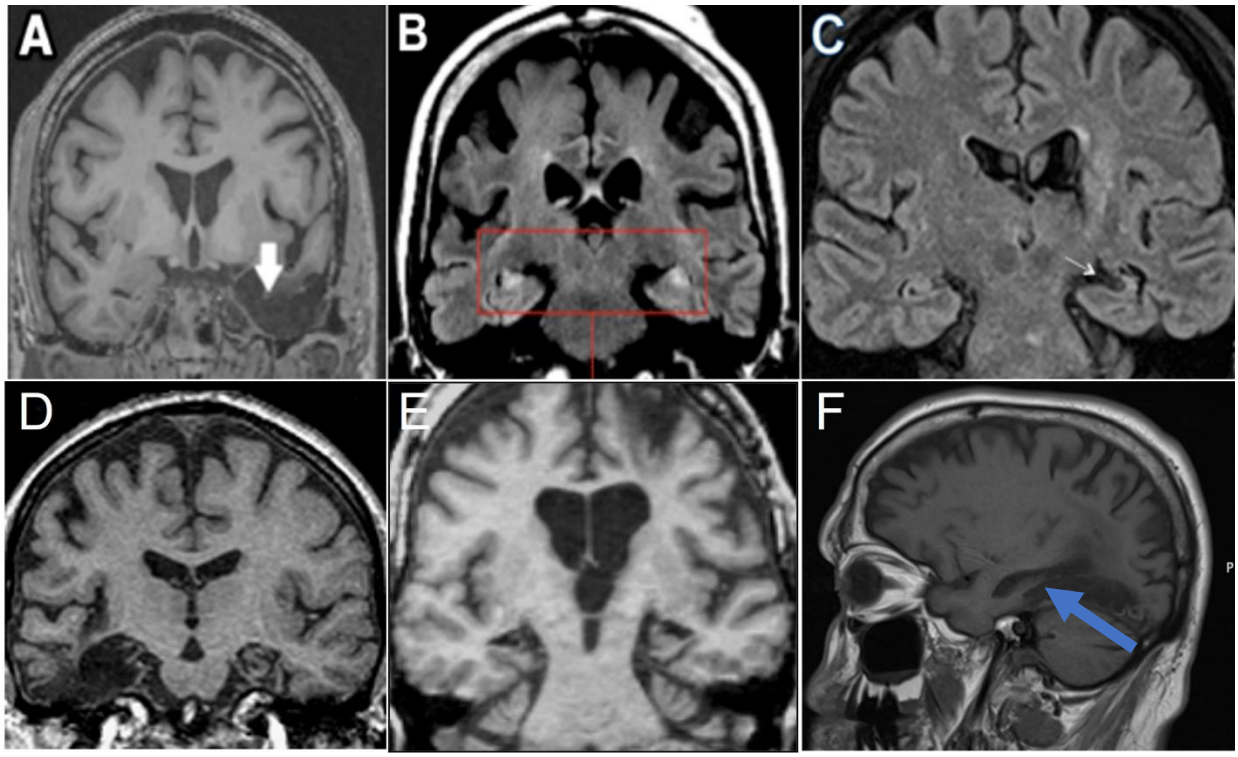

Figure 2.2. MRI images of MTL cases. Coronal T1-weighted image of medial temporal lobe damage for L.D. (A), B.L. (B), S.N. (C), D.A. (D), and K.C. (E). Sagittal T1-weighted image showing hippocampal volume loss for M.H. (F). Images are presented according to radiological convention (i.e., right hemisphere is presented on left side of image). Patients D.G., J.D., and J.M. could not be scanned because of contraindication. Scan for R.V. was unavailable. Details of lesion location and size are provided in the manuscript, and etiology, demographic information, and neuropsychological profiles are presented in Table 2.1.

Table 2.1. Demographic and Neuropsychological Data for vmPFC and MTL Participants

								Word List Learning			ROCF	
Case	Etiology	Age	Sex	Edu	IQ/PF	WCST	LF	AQ	LDFR	Recog	Copy	DR
vmPFC												
C.R.	ACoA	54	M	17	99	-	-	1%	<0.7%	<0.7%	68-70%	1-2%
M.T.	ACoA	50	M	12	98	>16%	20%	4%	<0.7%		84-86%	13%
R.L.	ACA	76	F	16	102	-	40%	81%	50%		66-68%	61-63%
M.M.	ACoA	58	M	18	98	>16%	<2%	8%	6-7%	<0.7%	22-23%	18-19%
J.W.	ACoA	58	F	15	99	>16%	30-40%	1%	<0.02%	30-32%	1-2%	13%
S.B.	ACoA	45	M	12	116	-	50%	1%	<0.03%	<0.02%	58-61%	<1%
M.P.	ACoA	54	F	13	103	11-16%	30%	2-3%	2-3%	-	8%	42%
J.A.G.	ACoA	65	F	15		-	50-60%	1%	<0.7%	3-9%	70%	2-3%
MTL												
D.A.	Encephalitis	62	M	17	117	>16%	21-32%	<1%	<1%	<0.02%	>99%	<1%
D.G.	Anoxia	48	M	16	92	>16%	7-13%	3-8%%	3-6%	<0.02%	21-32%	<1%
L.D.	TLR	61	M	19	111	>16%	21-32%	<1%	<1%	-	1%	21-32%
S.N.	Stroke	46	M	12	114	6-10%	21-32%	0.05%	<0.02%	<1%	21-32%	1%
B.L.	Anoxia	52	M	13	92	>16%	58-68%	21-32%	14-19%	<0.7%	14-19%	3-6%
K.C.	TBI	62	M	16	99	>16%	7-13%	<1%	<1%	<0.02%	>99%	<1%
R.V.	Stroke	51	M	16	104	11-16%	7-13%	1%	<1%	<0.02%	14-19%	<1%
M.H.	Encephalitis	56	M	13	110	>16%	21-32%	7-13%	2-3%	<0.02%	70-81%	3-6%
J.M.	Anoxia	51	M	16	95	>16%	2-3%	<1%	<1%	<0.02%	<1%	<1%
J.D.	Anoxia	64	M	19	240	>16%	7-13%	13-14%	<1%	50%	-	-

Note: Age: age in years; Edu: education in years; ACoA: Anterior Communicating Artery; ACA: Anterior Cerebral Artery; IQ: Full Scale IQ; for vmPFC, based on Wechsler Adult Intelligence Scale-IV for C.R., S.B., and M.P.; PF: Premorbid Functioning; based on

National Adult Reading Test for M.T. and M.M.; Wechsler Test of Adult Reading for R.L. and J.A.G. (vmPFC); FSIQ based on Wechsler Adult Intelligence Scale-Revised for D.A., D.G., and K.C., Wechsler Adult Intelligence Scale-III for L.D. and S.N., Wechsler Adult Intelligence Scale-IV for B.L., R.V., and M.H. (MTL);

The following were reported in percentiles compared to normative samples: WCST: Wisconsin Card Sorting Task; LF: Letter Fluency; for Word List Learning, learning based on Wechsler Memory Scale Verbal Paired Associates for M.P. and J.A.G., Hopkins Verbal Learning Test – Revised for L.D., Kaplan Baycrest Neurocognitive Assessment, Word List Learning for S.N.; California Verbal Learning Test-II for all others; for Stories (WMS): LM I/II: Logical Memory I/II; ROCF: Rey-Osterrieth Complex Figure Test; DR: Delay Recall.

See Appendix A for psychometric conversion table.

Table 2.2. Performance on a Galton-Crovitz Cue Word Test of Episodic Prospection in vmPFC and MTL Patients

	Internal details			External details		
Case	Z-score	% Rank	Descriptive Label	Z-score	% Rank	Descriptive Label
vmPFC						
C.R.	-2.48	< 0.9th	Severely Impaired	-1.26	< 12th	Low Average
M.T.	-	-	-	-	-	-
R.L.	0.38	> 63rd	Average	-0.90	< 19th	Low Average
M.M.	-2.02	< 3rd	Borderline	-1.03	< 16th	Low Average
J.W.	-	-	-	-	-	-
S.B.	-1.97	< 3rd	Mild-Moderately Impaired	0.92	82nd	High Average
M.P.	-2.40	< 0.9th	Severely Impaired	-1.76	< 4th	Borderline
J.A.G.	-1.79	< 4th	Borderline	-1.42	< 8th	Borderline
MTL						
D.A.	-1.65	< 5th	Borderline	-0.72	< 25th	Low Average
D.G.	-2.46	< 0.8th	Severely Impaired	-1.85	< 4th	Borderline
L.D.	-0.89	< 19th	Low Average	0.40	> 63rd	Average
S.N.	-2.07	< 2nd	Moderately Impaired	1.23	> 88th	High Average
B.L.	-1.43	< 8th	Borderline	1.46	> 92nd	Superior
K.C.	-2.68	< 0.4th	Severely Impaired	-2.20	< 2nd	Moderately Impaired
R.V.	-	-	-	-	-	-
M.H.	-2.28	< 2nd	Moderately Impaired	-1.47	< 8th	Low Average
J.M.	-2.28	< 2nd	Moderately Impaired	-1.91	< 3rd	Mild-Moderately Impaired
J.D.	-	-	-	-	-	-

Note: *Internal details* refer to episodic information (e.g., time, place, people, objects, thoughts, and emotions) specific to a central event that a person might experience in the future. *External details* refer to details that are not specific to the central event and/or that are semantic (factual) in nature and not specific to time and place, repetitions, commentary on the event, or other metacognitive

statements. Scoring of the Galton-Crovitz Task Episodic Prospection Task is based on internal and external details of the Autobiographical Interview (Levine et al., 2002). ‘High Average’ and ‘Superior’ performance indicate an excess of details. Patients scores are compared to scores of a demographically matched control group reported in Kwan et al. (2016)

Controls. Performance of 30 age-matched control participants (16 men; age range: 46-67 years, M = 58.4, SD = 6.3) was compared to that of each patient group on the delay and probability discounting tasks. Control participants were screened for variables associated with steeper than average discounting (Madden & Bickel, 2010), including smoking, significant alcohol and drug use, and gambling problems according to DSM-IV-TR/DSM-5 criteria. Exclusion criteria was based on self-report of previous or current clinical diagnosis, as well as current consumption of substances and partaking of these activities. Although 31 participants were tested, one proved to be a significant outlier on the probability discounting task and was excluded from all subsequent analyses. All participants were fluent in English. Participants gave informed written consent and received monetary compensation in accordance with the Human Research Ethics Committees of York University and Baycrest Health Sciences.

Delay Discounting

All participants completed the same computerized delay discounting task that had been used previously to test several of the participants with MTL lesions (Kwan et al., 2012; 2013). Each block, participants were presented with pairs of hypothetical monetary amounts and made choices between a smaller, immediate reward and a larger, delayed reward. They were told that the task assessed their preferences and that there were no correct or incorrect choices. An immediate reward amount, which changed depending on participants' previous choices and followed an up-down staircase titration method, was presented along with a fixed larger delayed reward amount ($100 or $2000) that was available after one of seven delays (1 week, 1 month, 3 months, 6 months, 1 year, 3 years, 10 years). These delays and the delayed reward amount remain the same across one block, but the order of appearance for each delay period was presented in a random order for each participant. Across six trials for each block, an iterative,

adjusting-amount procedure converged on the estimate of the amount of immediate reward that the participant judged to be subjectively equal in value to the delayed reward. For example, in the condition where a future hypothetical reward of $2000, if chosen, would be received in 3 months, the first choice presented to the participants was “$1000 right now or $2000 in 3 months?” If the participant chose “$1000 right now”, the choice on the second trial would be between “$500 right now” and “$2000 in 3 years.” If the participant chose “$2000 in 3 months,” the choice on the third trial would be “$750 right now or $2000 in 3 months.” Thus, adjustments in the amount of immediate reward were made such that the first adjustment was half the difference between the immediate and delayed reward amounts presented on the first trial, with each subsequent adjustment being half the preceding adjustment. Following the sixth and final trial of each delay condition, the subjective value of the delayed reward was estimated as the amount of immediate reward that would be presented if there were a seventh trial (see Green & Myerson, 2004). In total, participants completed 14 blocks of six trials, with one block for each of the seven delays for the smaller and larger reward amounts.

Probability Discounting

Patients and controls also completed a probability discounting task previously described in Kwan et al. (2013). For patients, the probability discounting task was completed on the same day as the delay discounting task, which was completed first, with a 30-45 minute interval between discounting tasks, during which the participants completed questionnaires and other behavioural tasks unrelated to the discounting tasks (not reported in the current study). Control participants completed both discounting tasks in a counterbalanced order on separate days, with 1-3 weeks between the tasks.

Participants were told that the task assessed their preferences and that there were no correct or incorrect choices. Each block, participants were presented with pairs of hypothetical monetary amounts and made choices between a smaller, certain reward that adjusted according to an up-down staircase titration method over six trials and a larger, fixed probabilistic reward. For each of the two fixed probabilistic amounts ($250 and $2,000), participants were asked to make choices between certain rewards and probabilistic rewards with a 90%, 75%, 50%, 20%, 10%, or 5% chance of receiving the reward, with these probabilities remaining the same within each block but having the blocks presented in random order for each participant. As in the delay discounting task, an iterative, adjusting-amount procedure was used in which the amount of the certain reward changed depending on the participant's previous selection. Across six trials, this procedure converged on an estimate of the amount of certain reward that the participant judged to be subjectively equal in value to the probabilistic reward. For example, in the condition where a reward of $2000 had a 50% chance of being received, the first choice was "$1000 for sure or $2000 with a 50% chance?" Adjustments in the amount of the certain reward were made such that the first adjustment was half of the difference between the certain and probabilistic amount presented on the first trial, with each subsequent adjustment being half the preceding adjustment. Following the sixth and final trial of each probability condition, the subjective value of the probabilistic reward was estimated as the amount of certain reward that would be presented if there were a seventh trial. In total, participants completed 12 blocks of six trials, with one block for each of the six delays for the smaller and larger reward amounts.

Area-under-the-Curve (AuC)

The degree to which a participant discounted delayed and probabilistic rewards was assessed using the AuC discounting measure. The AuC is theoretically neutral in that it

represents the area under observed subjective values rather than under a curve representing a particular theoretical model fit to those subjective values (Myerson et al., 2001). The 'curve' is actually a series of lines on a graph with the delays until or odds against receiving a reward expressed as a proportion of the maximum delay or odds against and the subjective values expressed as a proportion of the maximum delayed or probabilistic amount. Note that the odds against a probabilistic reward are equal to $[(1-p)/p]$, where p is the probability of receiving the reward.

AuCs are calculated by first normalizing the delays, odds against, and subjective values to make it easier to compare the discounting of different reward amounts. The area under the discounting curve is then subdivided into trapezoids, and the area of each trapezoid is calculated as $A = (x_2-x_1)(y_1+y_2)/2$, where values of x represent successive delays or odds against, and values of y represent subjective values associated with these delays or odds against. The AuC represents the sum of the areas of all the trapezoids and can range from 0.0 (maximal discounting) to 1.0 (no discounting).

Description of Statistical Analysis in Study 1

Because our plan was to compare each patient group's discounting rate to baseline measures based on a single, larger control group, we began our analyses by assessing the representativeness of our participant groups and the reliability of our discounting measures and procedures. We did this by examining the internal consistency of the AuC data for our participant groups on each type of discounting task and the degree to which their performances met benchmarks established based on previous studies of discounting in healthy adults (for a review, see Green & Myerson, 2010).

We then subjected all of the AuC data to a single 3 (Group) x 2 (Task) x 2 (Amount) mixed ANOVA, with Task (delay, probability) and Amount (smaller, larger) as repeated measures factors. We were primarily interested in possible differences in discounting between the lesion groups, although differences would likely have to be interpreted in light of any observed interactions. Based on previous reports that amount has opposite effects on delay and probability discounting in healthy participants, we predicted that type of Task would interact with Amount, perhaps even cancelling out the effects of amount. However, the effects of Amount might also be different for different groups and/or types of task, leading to a three-way interaction between Group, Task, and Amount that might well cancel out the effects of Group.

Accordingly, our three-way ANOVA was followed by four planned comparisons, each of which compared the control group to a specific lesion group performing a specific task (i.e., delay discounting by MTL patients, delay discounting by vmPFC patients, probability discounting by MTL patients, and probability discounting by vmPFC patients) of both reward amounts in order to explicate the observed pattern of interactions. Finally, because the hypothesis of individual differences in a general impulsiveness trait predicts that individuals who show steep delay discounting will also show shallow probability discounting, we examined the correlation between delay and probability discounting for each group separately.

Results

We begin our analyses of the AuC data by assessing the internal consistency of the discounting measures in our patient groups. This is especially important for the vmPFC group because previous studies have noted increased vmPFC activity during irregular preference judgements (Kurtz-David et al., 2019) and, in patient studies, more erratic judgements and greater inconsistencies in choice selections under conditions of uncertainty (e.g., risky or

ambiguous decisions) have been observed for patients with focal damage to the vmPFC compared to age- and education-matched controls (Fellows, 2011; Fellows & Farah, 2007; Henri-Bhargava et al., 2012). In fact, additional research has shown that the vmPFC may even be more specifically involved in value-based decision-making for risky choices across both human and animal models (Abela & Chudasama, 2012; Spaniol et al., 2019; Weber & Huettel, 2008).

We first identified whether inconsistent preferences were observed for each individual participant across both discounting tasks, separately for the smaller and larger reward amount conditions. For delay discounting, a monotonically decreasing discounting curve is expected when the subjective value (R_1) of the future outcome R at a given delay (t_1) is greater than the subjective value (R_2) at the immediately following delay (t_2) (where $t_2 > t_1$) (Johnson & Bickel, 2008). In accordance with the method proposed by Sellitto et al. (2010), we accounted for variability in the data by counting the number of "inconsistent choices" where the subjective value R2 was greater than the subjective value R1 at the preceding delay by more than 10% of the amount of the future outcome (i.e., $R_2 > R_1 + R/10$). Neither the Small amount (vmPFC = 0.75; MTL = 0.80; Control = 0.33), $F(2, 45) = 2.83$, $p = .07$, $\eta^2_p = .11$, nor the Large amount (vmPFC = 0.75; MTL = 0.40; Control = 0.33), $F(2,45) = 0.84$, $p = .43$, $\eta^2_p = .04$, conditions revealed significant differences in the mean number of inconsistent choices across participant groups for the delay discounting task, replicating previous findings (Sellitto et al., 2010).

The same procedure also was applied for the probability discounting task. Unlike delay discounting, one-way ANOVA revealed a significant Group effect for the Small amount condition, $F(2,45) = 5.71$, $p < .01$, $\eta^2_p = .20$. Post-hoc comparisons revealed a significant difference between the mean number of inconsistent choices for the vmPFC group ($M = 0.875$) compared to the MTL group ($M = 0.00$), $t = 3.36$, $p < .01$, $d = 1.34$, after Bonferroni correction.

For the Large amount condition, one-way ANOVA also revealed a significant Group difference, $F(2,45) = 8.89$, $p < .001$, $\eta^2_p = .28$. Post-hoc comparisons revealed significant differences between the vmPFC group ($M = 1.25$) and the MTL group (M = 0.30), $t = 3.26$, $p < .01$, $d = 1.12$, as well as the vmPFC group with the Control group (M = 0.23), $t = 4.16$, $p < .001$, $d = 1.70$, after Bonferroni correction. These inconsistencies observed in probability discounting but not delay discounting supports our inclusion of the "control" MTL patient-lesion group and agrees with the notion that impaired preferences may be the result of vmPFC's contribution more to conditions of uncertainty and risk (Abela & Chudasama, 2012; Fellows & Farah, 2007; Weber & Huettel, 2008).

We also looked at the correlation between the degree of discounting of smaller and larger amounts for each of our participant groups. As expected, the vmPFC group showed strong correlations for both delay discounting ($r = .87$, $p = < .001$) and probability discounting ($r = .73$, $p < .05$). The MTL group did not show significant correlations between amounts for delay discounting ($r = .27$, $p = .45$), but showed strong correlations for probability discounting, which is the task of primary interest in the current study ($r = .92$, $p = < .001$), supporting the inclusion of the MTL patients as a patient comparison group.

We also assessed the control group in the same manner. Correlations between the degree of discounting of smaller and larger rewards were equally strong for our controls, regardless of whether the rewards were delayed ($r = .88$, $p < .001$) or probabilistic ($r = .89$, $p < .001$). In contrast, the correlation between measures of delay and probability discounting was not significant, regardless of whether the correlation between delay and probability discounting was assessed for each amount condition separately or whether the AuC measures for the Control group were averaged across the smaller and larger reward conditions ($r = .163$, $p = .389$). The

finding of a nonsignificant positive correlation between delay and probability discounting is consistent with the benchmark set by many previous studies of discounting in healthy adults (Green & Myerson, 2010). Finally, the Control group showed both of the benchmark magnitude effects commonly observed in healthy adults: shallower discounting of larger delayed rewards ($t = 3.87$, $p < .001$, $d = 0.71$) but steeper discounting of larger probabilistic rewards ($t = 5.78$, $p < .001$, $d = 1.06$).

With the patient and neurotypical control groups established as appropriate comparison groups, the AuC data for all three groups were submitted to a 3 (Group) x 2 (Task) x 2 (Amount) mixed ANOVA. Although the main effect of Group was not significant, $F(2, 45) = 1.97$, $p = .151$, Group strongly interacted with Task, $F(2, 45) = 6.32$, $p = .004$, $\eta^2_p = .219$, consistent with the fact that the vmPFC group showed steeper delay discounting and shallower probability discounting than the other two groups. A three-way Group x Task x Amount interaction also was observed, $F(2,45) = 4.10$, $p = .023$, $\eta^2_p = .154$, consistent with the fact that larger group differences were observed in the larger amount condition. Finally, there was a significant Task x Amount interaction, consistent with the fact that, overall, the amount effects on the probability discounting task tended to be larger than those on the delay discounting task: $F(1, 45) = 5.73$, $p = .021$, $\eta^2_p = .113$.

Delay Discounting

Figure 2.4 presents group mean subjective values of the delayed rewards plotted as a function of the delay until their receipt. Both patient groups and control participants showed clear evidence of delay discounting as indicated by decreases in subjective value as the delay until the reward increased.

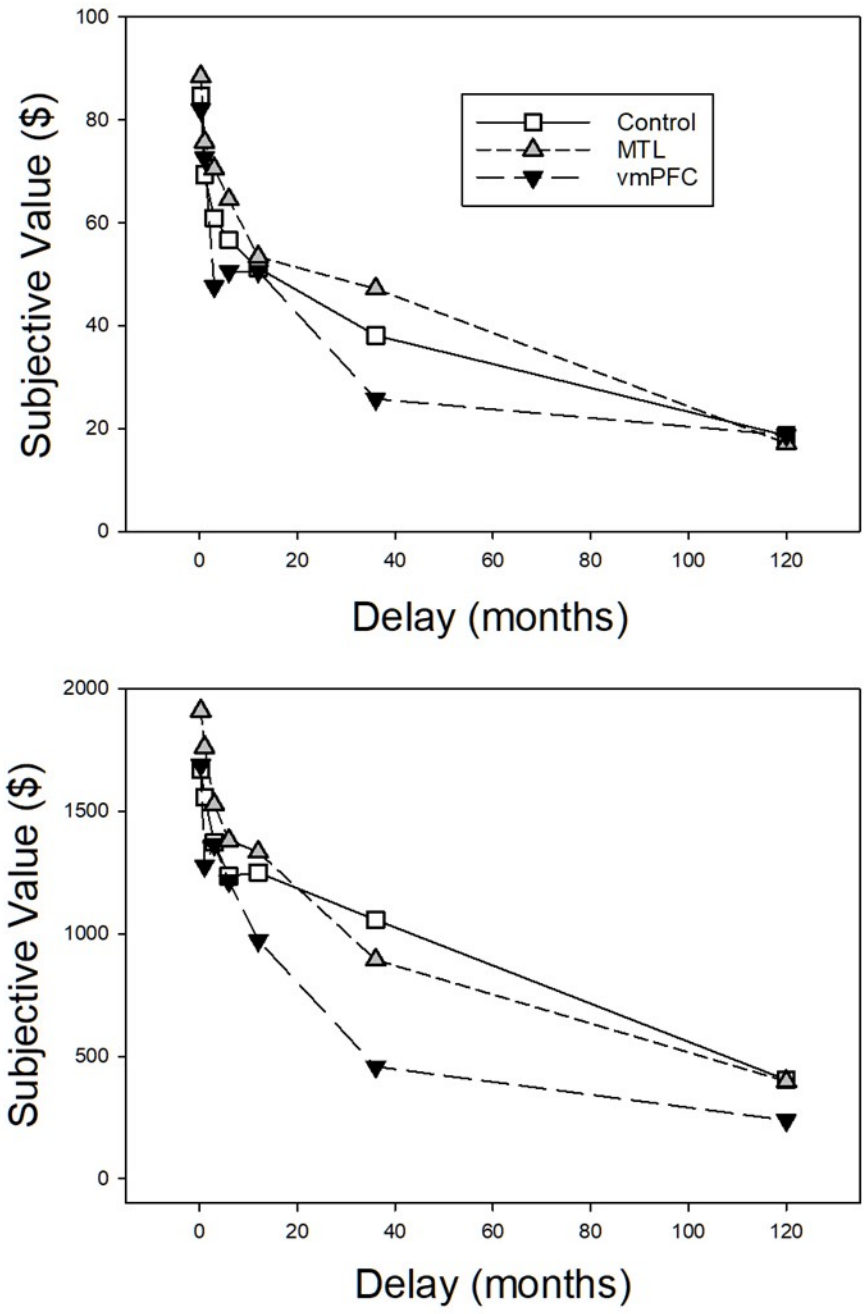

Figure 2.3. Mean subjective value as a function of delay until receiving the reward for the vmPFC, MTL, and control groups. The top and bottom panels present the data from the smaller ($100) and larger ($2000) delayed reward amount conditions, respectively.

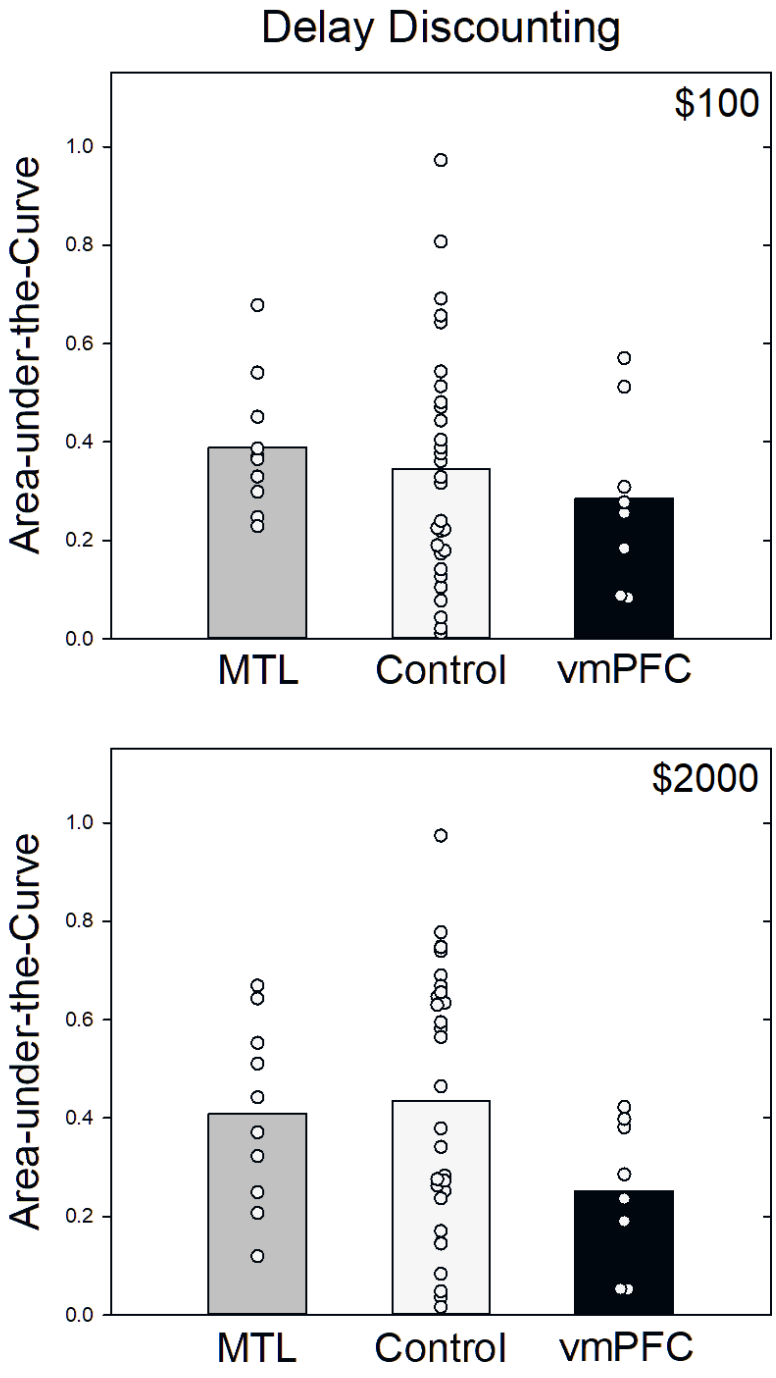

Figure 2.4. Mean Area-under-the-Curve (AuC) for the vmPFC, MTL, and control groups. The top and bottom panels present the data from the smaller and larger delayed reward amount

conditions, respectively. The circles represent individual participants' data from each group overlaid on their respective bars.

Group mean AuC scores are presented in Figure 2.4. The vmPFC patients appear to have discounted delayed rewards more steeply than the participants in the Control group, as indicated by their smaller AuCs. Only the Control group appears to show the usual magnitude effect in which smaller delayed rewards are discounted more steeply than larger ones (Green et al., 1997).

Our first planned comparison was conducted on the AuCs of the MTL and Control groups for the delay discounting task. Neither the main effect of Group nor the effect of Amount was significant: $F(1,38) = .011$, $p = .917$, and $F(1,38) = 4.08$, $p = .051$, respectively. The interaction between Amount and Group also failed to reach significance, $F(1, 38) = 1.73$, $p = .196$, although as noted previously, there was a significant effect of Amount (shallower discounting of larger delayed rewards) in the Control group.

Our second planned comparison, conducted on the delay discounting AuCs of the vmPFC and Control groups, also failed to reveal significant effects of Group or Amount: $F(1,36) = 1.74$, $p = .196$, and $F(1,36) = 1.43$, $p = .239$. However, these results must be interpreted in light of the significant interaction between Group and Amount, $F(1,36) = 6.50$, $p = .015$, $\eta^2_p = .038$, which suggests that the magnitude of the differences between the groups are significantly different between the two amount conditions. This is consistent with the fact that the difference between the patients and Control participants (i.e., steeper discounting by vmPFC patients) was larger for the larger delayed reward than for the smaller delayed reward condition although neither was significant (*p*s = .07 and .51, respectively) (see Figure 2.4).

Probability Discounting

Figure 2.5 presents group mean subjective values of the probabilistic rewards as a function of the odds against their receipt. Again, both patient groups, as well as the controls, exhibited discounting of both the smaller and larger rewards. In contrast to the delay discounting curves seen in Figure 2.3, however, the vmPFC patients tended to show higher subjective values for probabilistic rewards than MTL patients and participants in the Control group, particularly when the probability of reward was low (and the odds against were high).

Group mean AuC scores on the probability discounting task are presented in Figure 2.6. The vmPFC patients appear to have discounted probabilistic rewards less steeply than the participants in the Control group in both amount conditions, and less steeply than the MTL group in the large amount condition. Whereas both the MTL patients and the Control participants appear to have discounted smaller probabilistic rewards less steeply than larger ones, the vmPFC group discounted both smaller and larger amounts to approximately the same degree.

Our third planned comparison was conducted on the AuCs of the MTL and control groups for the probability discounting task. This analysis revealed a significant effect of Group, reflecting shallower discounting by the MTL group: $F(1,38) = 10.13$, $p = .003$, $\eta^2_p = .211$. There also was a significant effect of Amount $F(1,38) = 29.60$, $p < .001$, $\eta^2_p = .438$, consistent with the magnitude effect for probabilistic rewards usually observed in healthy participants. The interaction of Group and Amount was not significant, $F(1,38) = 1.70$, $p = .200$.

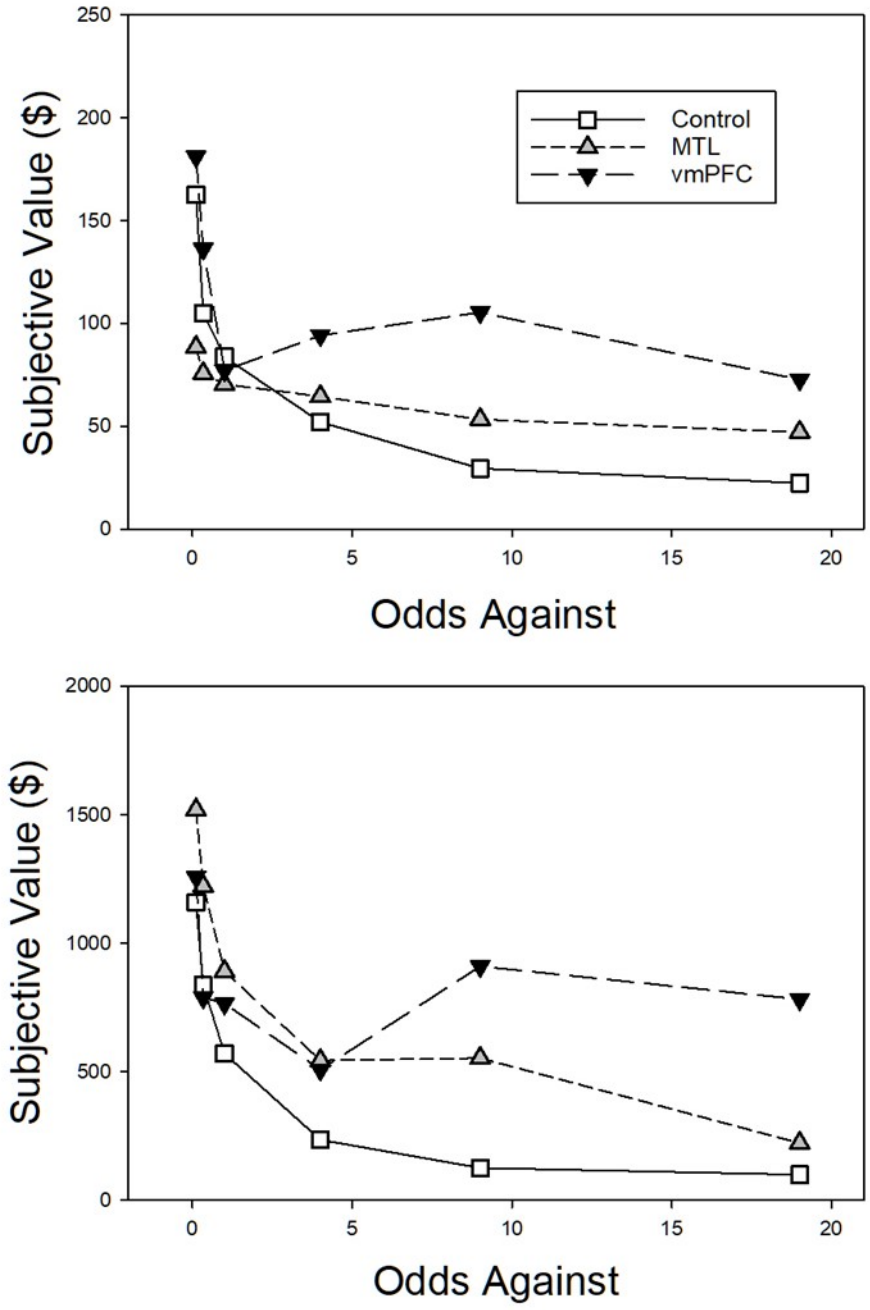

Figure 2.5. Mean subjective value as a function of the odds against receiving the reward for the vmPFC, MTL, and control groups. The top and bottom panels present the data from the smaller ($250) and larger ($2000) probabilistic reward amount conditions, respectively.

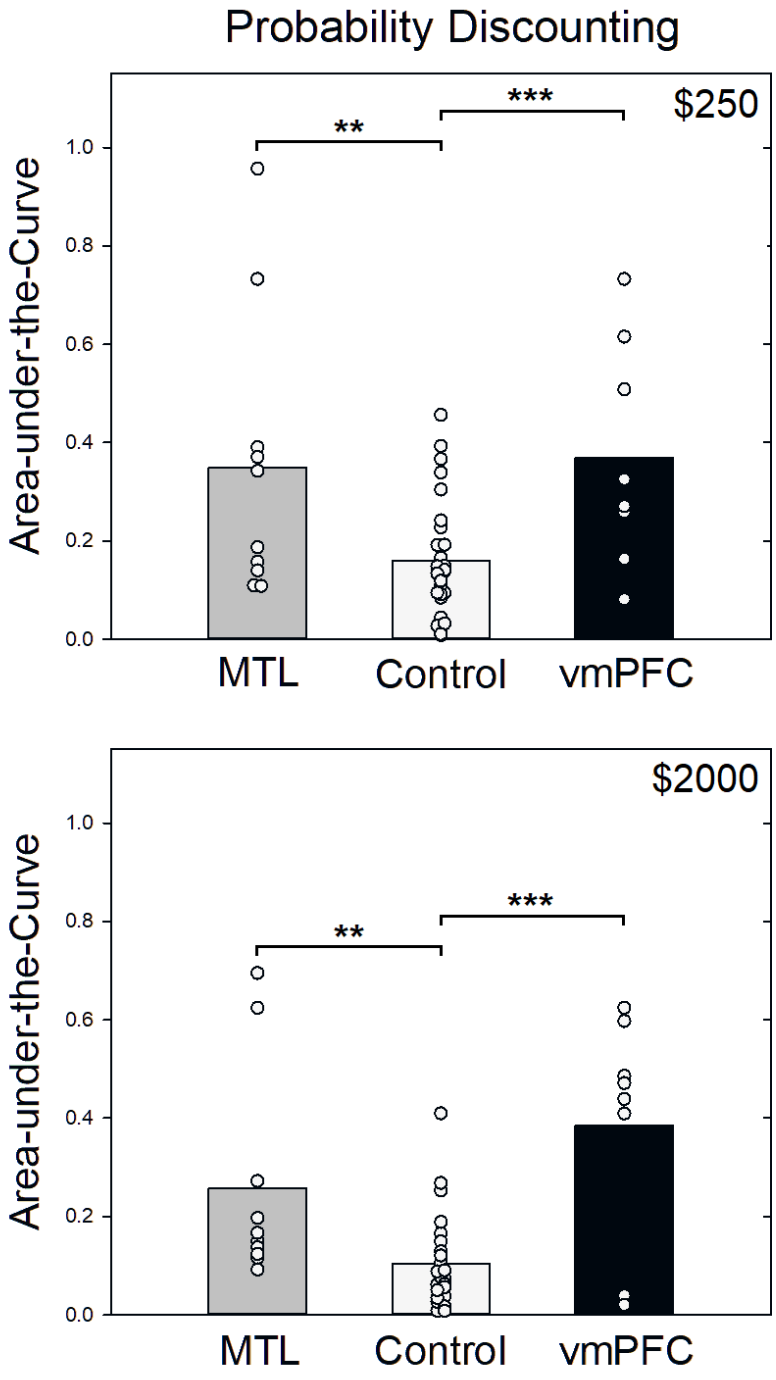

Figure 2.6. Mean Area-under-the-Curve (AuC) for the vmPFC, MTL, and Control groups. The top and bottom panels present the data from the smaller and larger probabilistic reward amount

conditions, respectively. The circles represent individual participants' data from each group overlaid on their respective bars. **$p < .01$. ***$p < .001$.

Finally, our fourth planned comparison focused on the vmPFC and control groups' probability discounting AuCs. There was a significant main effect of Group, $F(1,36) = 23.10$, $p < .001$, $\eta^2_p = .391$, which may reflect the shallower discounting of probabilistic rewards by the vmPFC group compared to the controls. Although the main effect of Amount was not significant, $F(1,36) = 1.28$, $p = .265$, there was a statistically significant interaction between Amount and Group, $F(1,36) = 4.27$, $p = .046$, $\eta^2_p = .106$, which may reflect the fact that while the vmPFC group's discounting showed little effect of reward amount, the Control group showed the magnitude effect for probability discounting (steeper discounting of larger probabilistic rewards) usually observed in healthy participants. Consistent with this interpretation, tests for simple main effects revealed group differences for both smaller and larger reward amounts: $F(1, 36) = 13.54$, and 30.40, ps $< .001$, respectively.

Relations between Delay and Probability Discounting

Our final set of analyses examined the relations between individuals' performance on the two types of discounting task. As already noted with respect to the Control group, the correlation between participants' delay and probability discounting was not significant: $r = .163$, $p = .389$ (see the top panel of Figure 2.7). A similar lack of significant correlation between delay and probability discounting was observed for the MTL group: $r = .214$, $p = .553$ (see the middle panel of Figure 2.7). Contrary to the idea that a unitary impulsiveness trait underlies both the ability to delay gratification and risk aversion, these correlations not only failed to reach significance, they also were in the direction opposite to that predicted.

The correlation between the vmPFC patients' delay and probability discounting was not only significant, $r = -.750$, $p = .032$, it also was negative (see the bottom panel of Figure 2.7), in contrast to the nonsignificant correlations observed for participants in both the MTL and neurotypical control groups. That is, the correlation for the vmPFC group was in the direction expected if these patients varied in impulsiveness, such that those who were less willing to wait (as indicated by their lower delay discounting AuCs) were also more willing to take risks (as indicated by their higher probability discounting AuCs).

Discussion

Financial choices are sensitive to the temporal proximity, likelihood, and amount of each option (Rangel et al., 2008), as is evident from the way neurotypical individuals tend to discount the value of delayed and probabilistic outcomes (Green & Myerson, 2010). However, a neurotypical individual's tendency to discount delayed rewards more or less steeply is relatively independent of their tendency to discount probabilistic rewards (Green & Myerson, 2013). The current study tested whether focal lesions that affect one type of discounting necessarily affect the other type, with the goal of revealing component processes shared by different forms of discounting. Importantly, we tested this idea at both the group level as well as at the level of the individual patient.

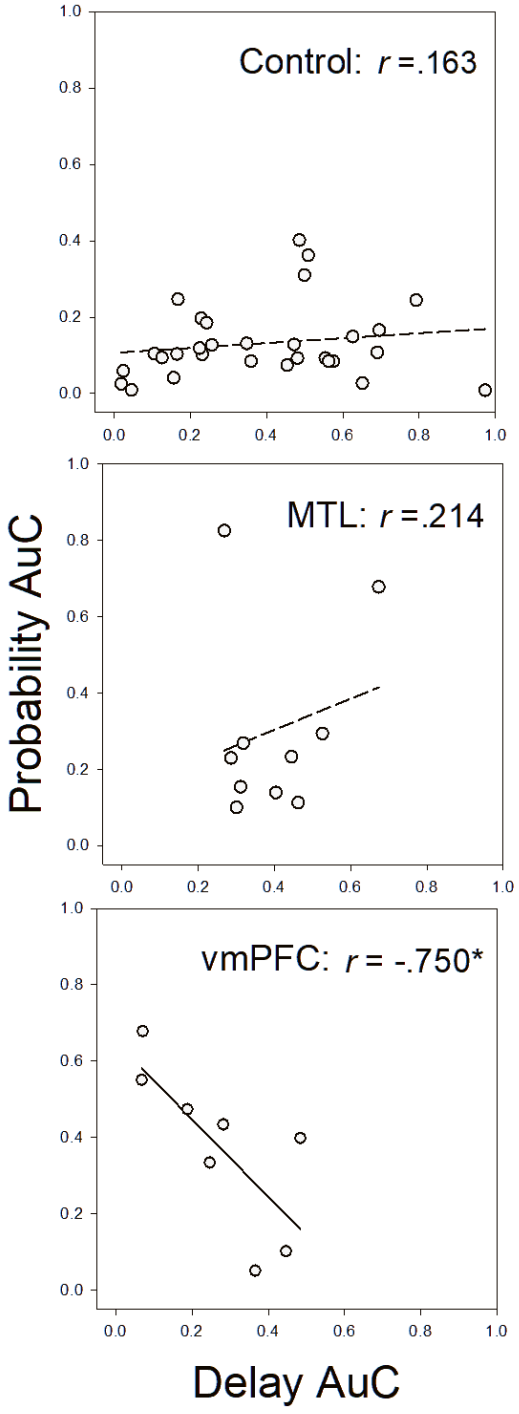

Figure 2.7. Individual mean AuCs (averaged across the two amount conditions) for the delay discounting task, plotted as a function of their mean AuCs for the probability discounting task.

Data for the control group are shown in the top panel, data for the MTL group are shown in the middle panel, and data for the vmPFC group are shown in the bottom panel.

In the current study, the vmPFC and MTL patient and control groups all showed systematic discounting of both delayed and probabilistic rewards, although important quantitative differences in degree of discounting were observed. On average, vmPFC-lesioned individuals discounted delayed rewards more steeply but discounted probabilistic rewards less steeply than controls, whereas MTL-lesioned individuals discounted delayed rewards at normal rates but discounted probabilistic rewards less steeply than neurotypical controls. These results suggest that vmPFC lesions affect the weighting of reward amount relative to delay and certainty in opposite ways.

Notably, patients with MTL lesions did not differ from controls in the degree to which they discounted delayed rewards, but compared to the controls, they discounted probabilistic rewards to a significantly lesser extent, suggesting that they put less weight on the likelihood of actually getting a reward. That is, they were more likely to gamble on the possibility of getting a reward, whereas the controls were significantly more risk averse. Importantly, some of these patients have extensive lesions affecting the hippocampus and surrounding MTL cortices (e.g., K.C., D.A.) and yet these patients are indistinguishable from controls in delay discounting despite impaired episodic memory and episodic future thinking. In contrast, patients with vmPFC lesions did tend to discount delayed rewards more steeply than the Control group, with the size of the difference increasing with the amount of reward; like MTL patients, they discounted probabilistic rewards less steeply than controls. Differences between the vmPFC and controls were amplified with larger reward amounts, reflecting the control participants' tendency

to be more risk averse when the stakes were higher, whereas the vmPFC patients were unaffected in this regard.

As Green and Myerson (2013) and others have noted, delay and probability discounting are similar in that in both cases, subjective value shows systematic, negatively accelerated decreases that are well described by hyperboloid functions (see Figures 2 and 4). They are different, however, in that in healthy adults, varying the amount of reward has opposite effects on delay and probability discounting (Green et al., 1999; Myerson et al., 2003). Myerson et al. (2003) further showed that the degree to which an individual discounts delayed rewards is, at most, weakly positively related to the degree to which that individual discounts probabilistic rewards. This finding, which was replicated in our analyses of participants in the Control group, argues against the hypothesis that delay and probability discounting represent a unitary underlying trait of impulsiveness in healthy adults. The unitary trait hypothesis implies that individuals' delay and probability discounting should be negatively correlated with one another. According to this view, impulsive individuals have both a strong preference for immediate rewards over delayed ones and a strong tendency to gamble on getting a large reward rather than a smaller, certain one, even though with the former, they risk getting no reward at all.

As already noted, the correlation between delay and probability discounting in the Control group was weakly positive, but not significantly so. Importantly, whereas a similar relation was observed in the MTL patients, the vmPFC patients showed a strong negative correlation between individual patients' delay and probability discounting (see Figure 2.7), a finding that would be expected if vmPFC lesions affected the degree of their 'impulsiveness.' The fact that, as a group, vmPFC patients also showed both steeper delay discounting and shallower probability discounting is consistent with that interpretation.

Previously, researchers examining the effects of vmPFC lesions in humans have primarily studied intertemporal choice, which includes delay discounting (Fellows & Farah, 2005; Peters & D'Esposito, 2016; Sellitto et al., 2010). Lesion studies on the vmPFC have also considered risky choice but have relied for the most part on laboratory-based gambling tasks or animal models (e.g., Bechara et al., 2000; St. Onge & Floresco, 2010; Spaniol et al., 2019), or have not observed consistent findings supporting comparative differences between patients and matched controls in probability discounting (Pujara et al., 2015). The overall patterns (i.e., steeper discounting for delayed rewards or preference for risky rewards compared to controls) have been reported, but the present study is among the first to observe both these patterns in the same patients (see also Peters & D'Esposito, 2020). Importantly, the present investigation did so by using analogous tasks specifically designed to facilitate direct comparisons of intertemporal and risky choice (Green & Myerson, 2004). It is also the first study to directly compare performance of vmPFC patients on both discounting tasks with that of MTL patients who have similar deficits in episodic future thinking. The results have important implications for the localization of function in decision-making and for the nature of the mechanisms involved.

Decision-making by intact brains

In neurotypical adults, there appear to be neural systems for which activity reflects valuation of both delayed and probabilistic rewards as well as other systems involved in domain-specific valuation (e.g., Seaman et al., 2018). Using fMRI to examine the neural bases of delay and probability discounting, Peters and Büchel (2009) found that activity in fronto-polar, lateral parietal, and posterior cingulate cortex correlated with the value of delayed, but not probabilistic, rewards, whereas activity in superior parietal cortex and middle occipital areas correlated with the value of probabilistic, but not delayed, rewards. Notably, activity in ventral striatum and

vmPFC coded for subjective value in a domain-general manner, suggesting that these regions integrate results from the domain-specific valuation systems into a common "neural currency" that is involved in value computation across tasks and is utilized across different reward types and stages of decision-making (Bartra et al., 2013; Levy & Glimcher, 2012; Rangel & Clithero, 2014). Furthermore, activity in these regions can be dissociated from activity in other reward valuation regions (including anterior insula, other striatal regions, and dorsomedial prefrontal cortex) involved in arousal, saliency of reward options, and meta-decision processes (e.g., confidence and deliberation time of choices) (see also Clairis & Pessiglione, 2020). Studying individuals with focal lesions to these brain regions provides more definitive evidence regarding the localization of function in decision-making mechanisms, particularly with respect to the issue of domain-general versus domain-specific processes.

Decision-making by brains with focal lesions

In the present study, patients with vmPFC lesions not only showed steeper delay discounting than controls, but they also showed shallower probability discounting, and within the vmPFC group, those who showed the steepest delay discounting also showed the shallowest probability discounting. These findings are consistent with the results of previous studies that investigated each kind of decision-making in isolation (for reviews, see Bechara, 2011; Sellitto et al., 2011). Sellitto et al. (2010) demonstrated that vmPFC lesions affect delay discounting (see also Peters & D'Esposito, 2016; but see Leland & Grafman, 2005), systematically increasing patients' preferences for immediate rewards even when those rewards are smaller than delayed ones. Although previous studies suggest vmPFC lesions also affect risky choice, the procedures usually required the participants to learn probabilities from experience (Iowa Gambling Task; Bechara et al., 1994; 1996). As a result, findings from these procedures may be confounded, as

studies comparing younger and older adults have shown (for a review, see Mata et al., 2011). That is, observed differences could reflect deficits in either decision-making, learning, or both.

Fortunately, the present probability discounting procedures do not require new learning by participants, and therefore our finding that vmPFC patients show shallower probability discounting than controls strongly support previous conclusions regarding the effects of vmPFC lesions on risky choice. Our results are consistent with those of a recent study of decision-making by Peters and D'Esposito (2020) that also found both steeper delay discounting and shallower probability discounting in patients with focal lesions to vmPFC/orbitofrontal than in controls. Consistent with previous work is the current finding that MTL patients' probability discounting was shallower than that of controls (Gupta et al., 2009; Gutbrod et al., 2006; Rosenbaum et al., 2016), and that their delay discounting did not differ from that of controls (e.g., Kwan et al., 2012, 2013). Notably, MTL patients' pattern of impaired probability discounting with preserved delay discounting provides additional evidence that the two kinds of discounting involve at least some separate processes.

Nevertheless, there still could be a cognitive process or processes common to both delay and probability discounting that might be affected by lesions of the vmPFC. The present findings provide an answer to Peters' (2011) question of whether vmPFC/orbitofrontal cortex damage affects only the valuation of delayed rewards, or whether it leads to "a more general impairment in cost-benefit decision-making that extends beyond the domain of intertemporal choice." The present findings support the latter view: patients with focal vmPFC lesions differed from controls in both the intemporal and risky choice domains, as indicated by performance on both delay and probability discounting tasks. The question that remains is why this might be so. Intuitively, it would seem likely that delay and probability discounting would involve a common process

because the future is inherently risky, but this intuition is not borne in the data: were this the case, vmPFC patients should have evinced steep probability discounting and should be risk-averse just as they are attracted to immediate rewards. In the present study, we found the opposite pattern.

One common process that may underlie performance on delay and probability discounting is prospection (see Gilbert & Wilson, 2007; Szpunar et al., 2014), a hypothesis we can test, as the current study involves two patient populations with important, yet qualitatively different, prospection deficits (Bertossi, Tessini, et al., 2016; Kwan et al., 2013, 2015; Rosenbaum et al., 2016; Verfaellie et al., 2019). Although prospection is more commonly associated with delay discounting (Boyer, 2008), some theories of risky choice posit that choices involving probabilistic outcomes also involve consideration of future outcomes (e.g., Loomes & Sugden, 1982). For example, regret theories of risky choice posit that gambles involve prospection in the form of imagining possible future outcomes (i.e., winning and losing the gamble and the regret that would follow a loss). The fact that both vmPFC patients and MTL patients show steep probability discounting, and that both groups fail to show consistent effects of reward magnitude, might support a link between discounting behaviour and prospection. However, the results observed on delay discounting argue against this possibility.

Although previous studies of the effects of episodic cueing demonstrate that prospection can play a role in delay discounting (e.g., Bulley et al., 2019; Mok et al. 2020; O'Donnell et al., 2017), patients with MTL lesions who have severe prospection deficits nevertheless exhibit typical, systematic discounting of delayed rewards. As an extension of our previous findings, this systematic discounting was observed at the group level and with a larger group of patients than previously described by Kwan et al. (2013). MTL patients also show the certainty and common

ratio effects (i.e., the Allais paradox; Craver et al., 2014), benchmark characteristics of risky choice that have been attributed to anticipated regret (Bell, 1982; see also Klein, 2013).

Importantly, in the present study, both patients with MTL lesions and patients with vmPFC lesions had deficits in prospection, but only the vmPFC group differed significantly from controls in delay discounting. One possibility is that although prospection can contribute to effective decision-making, and may even compensate for cognitive deficits, it is not required. Another possibility is that vmPFC and MTL patients have qualitatively different prospection deficits, and it is the form of prospection affected in vmPFC – but not MTL – patients that has an impact on the valuation, or even the conception, of future rewards. What then might be the common process or mechanism that underlies the observed effects of vmPFC lesions on delay and probability discounting? It should be noted, of course, that there need not be one. That is, the vmPFC could contain some neurons contributing to intertemporal decision-making and other neurons contributing to decisions involving risky options, or it could contain neurons that do both.

Delay and probability discounting require complex decisions involving multiple cognitive processes. It is possible that performance on both tasks depends on schemas, which refer to knowledge structures extracted across multiple experiences. Schemas influence how new events (e.g., choice options) are perceived, and they have been linked to the vmPFC in neuroimaging and patient-lesion studies (Ghosh et al., 2014; Hebscher & Gilboa, 2016; for a review, see Gilboa & Marlatte, 2017). Reliance on schemas could explain the surprising finding by Kwan et al. (2013) that MTL patients' delay discounting does not differ from controls despite the patients' deficits in prospection. These results hold in the current study, even with the addition of 7 new MTL patients to the patients described by Kwan and colleagues. MTL patients

may compensate for their episodic memory deficits by relying on schemas along with simple heuristics or even aphorisms that provide the basis for heuristics (e.g., sooner is better, a bird in the hand). Although vmPFC patients, like MTL patients, have prospection deficits, their schemas may be compromised, unlike those of MTL patients, leading to deficits in both delay and probability discounting for vmPFC (but not MTL) patients.

An explanation for the direction of the differences on the discounting tasks would not be necessary if impulsiveness were a basic behavioural tendency, as accounts that pit impulsiveness against self-control imply. If it were, then one could imagine a tendency towards impulsiveness being 'unmasked' or disinhibited by brain damage that somehow weakened self-control. However, correlational data from healthy adults do not support this view (for a review, see Green & Myerson, 2010). This view is also not supported in light of previous findings by Donald Stuss and colleagues who have shown that risk-taking can be dissociated from impulsiveness within prefrontal cortex (Floden et al., 2008). If anything, the data support the opposite view; other things being equal, the fundamental tendency may be to choose rewards that are both immediate and certain, since people generally prefer their rewards to come sooner and with greater certainty.

Reward size also matters. People tend to want more (i.e., larger rewards), and they want their rewards sooner and for sure. Reward amount is frequently pitted against immediacy and certainty in choice situations. In light of the present findings, the critical question no longer appears to be whether the vmPFC's contribution to decision-making concerns valuation or prospection, as Peters (2011) had suggested. Rather, the issue is how and why vmPFC lesions *decrease* the weight given to a reward's amount relative to its immediacy, as reflected in steeper delay discounting, but *increase* the weight given to a reward's amount relative to its likelihood,

as reflected in shallower probability discounting. An adequate account of the effects of vmPFC lesions will need to explain the differential weighting of reward amount depending on whether a reward is delayed or probabilistic. It is unclear at this time how a single mechanism could underlie both of these effects given that this pattern of behaviour is not at all observed in controls and likely plays no significant role in reward discounting in neurotypical individuals.

Conclusions

Discounting is an especially interesting aspect of decision-making for two reasons: first, because the outcomes of everyday choices typically have multiple attributes and discounting focuses specifically on the problem of attribute-integration, and second, because the relative weighting of attributes like immediacy and likelihood appears to underlie many important behavioural problems at both the individual (e.g., substance abuse) and societal (e.g., climate change, pandemic) levels. If the vmPFC is functionally heterogeneous, then integration of immediacy and amount (delay discounting) might well be a separate function from the integration of likelihood and amount (probability discounting). This view raises the possibility that integration of other outcome attributes in decision-making and reward discounting may also involves separate functions, although it should be noted that separate functions do not require separate substrates (i.e., locations) or even separate neurons, just separate circuits. Nevertheless, the functions of the vmPFC appear to be key to understanding such attribute-integration issues, and as the present study shows, focal lesion patients can provide insight into these issues, particularly when the same patients are studied using tasks like delay and probability discounting that require integration of different attributes.

Adapted from:

Mok, J. N.Y., Green, L., Myerson, J., Kwan, D., Kurczek, J., Ciaramelli, E., ... & Rosenbaum, S. R. (2021). Does Ventromedial Prefrontal Cortex Damage Really Increase Impulsiveness?

Delay and Probability Discounting in Patients with Focal Lesions. *Journal of Cognitive Neuroscience*, 1-19.

CHAPTER 3

Study 2: Comparing delay and probability discounting with and without episodic cues in young and older adults

In Study 1, we investigated the differences between standard delay and probability discounting in healthy adult controls and vmPFC and MTL patient groups. Findings that there are opposite effects in the weighting of different delayed and probabilistic reward amounts in some patients (i.e., individuals with vmPFC lesions) but not healthy controls suggest that reward valuation and impulsivity may play a role during typical reward discounting. In the present study, the focus turns specifically to the function of episodic simulation across reward choices. By remembering the past and imagining the future, we can simulate both how we and other people might feel and think in other conditions, places, and times. These personal, imagined experiences may allow us to plan for the future, consider different options, and engage in more precise, goal-directed decisions (Boyer, 2008; Kahneman & Miller, 1986; Taylor & Schneider, 1989). The extent to which episodic memory and imagining exert a modulatory effect on decision-making, however, may depend on both the age of the decision-maker and on whether the decision is future-oriented or involves a probabilistic outcome.

The adaptive value of episodic imagining for human decision-making has been well studied in the context of intertemporal choice, leading to a fruitful partnership between cognitive neuroscience and behavioural economic approaches. Boyer (2008) suggested that imagining and constructing future experiences may guide people towards suitable delayed outcomes and away from near-sighted choices, bringing long-term outcomes closer in subjective time to the present. This tendency may be enhanced when people are prompted with personal cues of vivid events or actions (for a review, see Bulley et al., 2016). Such effects of personal cues have been observed in diverse populations, including not only healthy young adults (for a meta-analytic review, see

Rung & Madden, 2018), but also individuals with behavioural problems, such as gambling, alcohol abuse, and eating disorders (e.g., Appelhans et al., 2011; Bulley & Gullo, 2017; Mellis et al., 2019; Wiehler et al., 2015), as well as individuals living in poverty (O'Donnell et al., 2019) and adolescent children (Bromberg et al., 2015; 2017). This effect has been observed with different kinds of cues, for example, when participants are asked to imagine what they would do with consumable and non-monetary delayed rewards (e.g., Benoit et al., 2011), generate semantic uses for rewards (Palombo et al., 2016), reflect on general or specific future events involving themselves (e.g., Cheng et al., 2012; Dassen et al., 2016; Nan & Qin, 2018), or imagine an episode not previously experienced (e.g., Sasse et al., 2015). The vividness, recency, and frequency of the cues have also been shown to affect the degree of discounting (e.g., Daniel et al., 2015; Lin & Epstein, 2014; Liu et al., 2013; Mellis et al., 2019).

To date, however, no consensus has emerged regarding the effects of aging on delay discounting (for a review, see Mohr et al., 2010), and little is known regarding the effects of episodic cueing in older adults. Choice of future rewards over immediate rewards in young adults may be positively influenced by imagining specific future episodes, but whether older adults obtain a similar benefit is less clear. Some researchers have argued that older adults have a more myopic view of the future (Liu et al., 2016; Read & Read, 2004; Seaman et al., 2016) and are more inclined to forego delayed gratification and to pursue immediate satisfaction, given the increased risk of poor health and financial instability that comes with aging (Carstensen et al., 1999). Others, in contrast, have argued that increased self-control and changes to lifestyle factors in healthy aging (e.g., interpersonal social roles, health considerations, and prosocial altruism) may lead to reduced discounting of future rewards in older adults compared to young adults (Löckenhoff et al., 2011; Sparrow & Spaniol, 2018). Moreover, older individuals could

experience time as being "more compressed and fast-paced" (Sparrow & Spaniol, 2016), and this change in how time is perceived could, in turn, reduce the subjective distance of future rewards (Kim & Zauberman, 2009; Lempert & Phelps, 2016; Rutt & Löckenhoff, 2016; Wittmann & Lehnhoff, 2005). Nevertheless, some studies that included comparisons of older adults with middle-aged adults or even with adults in their 30s, have failed to find age-related differences in delay discounting (Chao et al., 2009; Green et al., 1996), while others have reported greater delay discounting by older adults (e.g., Read & Read, 2004), and still others have reported less discounting by older adults (e.g., Green et al., 1994; Löckenhoff et al., 2011; Reimers et al., 2009).

Regardless of whether younger and older adults differ in the degree to which they discount the value of future rewards, there is reason to suspect that older adults may show smaller effects of episodic cueing. Indeed, in a recent study by Sasse et al. (2017), older adults made choices involving delayed rewards while simultaneously imagining themselves interacting with another person at a café on the date of a delayed reward delivery; such cues failed to decrease the degree to which the value of the reward was discounted. In fMRI experiments on intertemporal choice, the effects of episodic imagining appear to be mediated by activity in the hippocampus/MTL and vmPFC, at least in young adults. Participants were more inclined to select larger, delayed rewards over smaller, immediate rewards when an episodic event cue was presented alongside the delayed reward option; this preference was accompanied by increased activity within, and coordination between, the hippocampus/MTL and vmPFC (Benoit et al., 2011; Peters & Büchel, 2010). Moreover, the degree of coupling of activity between these areas of the brain predicted the degree to which young adults discounted the value of future rewards (Peters & Büchel, 2010).

Although older adults' MTL and vmPFC are also engaged when they are imagining future events, this activation is lower than that observed in younger adults (Addis et al., 2007; Buckner & Carroll, 2007). From the perspective of Schacter and Addis' (2007) constructive episodic simulation hypothesis, age differences may occur because imagining future scenarios is more demanding than retrieving past episodes, and regions of the prefrontal cortex involved in such imaginings are known to change with age. Another possibility is that the difference in activation reflects older adults' decreased hippocampal volume and their greater reliance on semantic content when they imagine future events (Addis et al., 2008; 2010; Gaesser et al., 2011; Grilli et al., 2018; Levine et al., 2002; St. Jacques & Levine, 2007). Previous research from our research group (Kwan et al., 2012; 2013) reported that individuals with MTL damage and associated deficits in episodic imagining did not differ from controls in the degree to which they discounted delayed rewards. However, amnesic individuals were less likely to benefit from episodic cues, and the benefit they received may require that cues be both personally relevant and adjacent to the presented options (Kwan et al., 2015; Palombo et al., 2015b). Therefore, the procedure in the present study was modeled after that used by Kwan et al. (2013) in order to determine whether older adults would show less of an episodic cueing effect than younger adults even under such conditions.

One important aspect of decision-making that has received little study concerns the role of episodic imagining in the discounting of probabilistic rewards. Just as the subjective value of future rewards decreases as the time until their receipt increases, the subjective value of probabilistic rewards decreases as the odds against their receipt increase. Both delay and probability discounting are best described by a hyperboloid function (for a review, see Green et al., 2014). Indeed, some have postulated that the same or, at least, largely overlapping processes

underlie both delayed and probabilistic decisions-making (Rachlin et al., 1991). Moreover, it has been hypothesized that decisions regarding probabilistic rewards involve some form of episodic imagining by way of anticipating the regret that would follow the failure to receive a reward (e.g., Loomes & Sugden 1982; cf. Craver et al., 2014). To date, however, few studies have examined the effect of cueing on probability discounting unconfounded by the effects of delay. One earlier study examined cueing on probability discounting involved a confounding paradigm where a small sample of participants made risky choices but in the context of future outcomes (Kaplan et al., 2016). A more recent study by Bulley et al. (2019) had participants imagine future events based on positively or negatively valenced word cues prior to completing a delay discounting task and a risk-taking task (i.e., balloon-analogue risk task; BART) and found that although both positive and negative episodic cues decreased delay discounting, they had no effect on risk taking. It should be noted, however, that the BART involves potential losses as well as gains, and thus comparisons of choices on the BART and the discounting of delayed rewards are confounded by differences in the valence of the outcomes. And for both studies described, the generalizability to an older adult population was not considered.

Thus, it remains unclear whether aging has similar effects on decisions involving delayed outcomes as it has on decisions involving probabilistic outcomes. A meta-analysis of age-related differences in risky choice by Mata et al. (2011) revealed that when decisions are based on explicit information about the risks involved, as in most standard risky choice and probability discounting tasks, there tend not to be age differences observed, regardless of whether the risky options involved gains or losses. In contrast, when the information about risk is not explicitly provided and participants have to acquire it based on their experience during the experimental session, as on the Iowa Gambling Task, age differences are usually observed. As noted

previously, however, no consensus exists as to whether there are age-related differences in delay discounting, and little is known about whether age modulates the effects of episodic cueing on the discounting of either delayed or probabilistic rewards. Accordingly, the present study examined the effects of cueing in both young and older adults, not only on the discounting of delayed rewards (Experiment 1 of Study 2) but also, for the first time, on the discounting of probabilistic rewards (Experiment 2 of Study 2).

Experiment 1 – Delay Discounting

In previous studies examining the effects of episodic cueing on delay discounting in patients with MTL damage (Kwan et al., 2015; Palombo et al., 2015b), cueing produced a significant decrease in discounting by the older adult control groups; however, Sasse et al. (2017) failed to replicate this finding at the group level, although when comparisons were made between older adults with higher and lower cognitive ability, those with higher ability were more affected by cueing than those with lower ability. Accordingly, our primary research questions for the present experiment concerned the reliability of episodic cueing effects in older adults, and, assuming the Kwan et al. (2015) findings replicate, whether there are age-related differences in the magnitude of such cueing effects. Previous studies have observed diminished ability to engage in future-oriented thought as a function of age (Addis et al., 2008, 2010; Gaesser et al., 2011), leading to the expectation that episodic cueing will affect older adults less than young adults. In the present experiment, delay discounting was studied with two amounts of delayed reward because it is well-established that larger rewards are discounted less steeply than smaller rewards (for a review, see Green & Myerson, 2004), and replication of this benchmark finding helps establish the validity of both our approach and our findings.

Experiment 1 – Methods

Participants

Sample size for the current study was based on the expected effect size. Re-analysis of the data from the age- and education-matched older adult control group in our previous study of episodic cueing and delay discounting in patients with MTL damage (Kwan et al., 2015) revealed that the size of the cueing effect in healthy older adults, averaged across two reward amounts, was large (Cohen's d = .88). According to Cohen (1988), samples of 26 participants per group would provide more than adequate power (>.80 with α = .05) for an effect of this size; however, because of the discrepancy between the Kwan et al. (2015) and Sasse et al. (2017) results, larger samples were studied in the present experiment. The young adult group consisted of 58 undergraduate-level students from York University (26 females; M = 20.0 years, SD = 2.82); the older group consisted of 56 older adults (28 females; M = 64.1 years, SD = 8.58). No sex differences were observed for either age groups (ps > .05). Participants were screened for behaviors associated with steep discounting of delayed rewards (Madden & Bickel, 2010), including smoking and illicit drug use as well as alcohol and gambling problems, according to DSM-IV-TR and DSM-5 criteria. Participants included here do not include any individuals who meet criteria for any of the stated behaviours nor have they reported current consumption of these substances or undertaking of these activities.

We emphasize that although the current report is divided into Experiments 1 and 2 for ease of understanding, this, in some cases, misrepresents the order in which the participants performed the two discounting tasks. Although some participants performed only the delay discounting task, the majority of the young and older adult participants performed both delay and probability discounting tasks, and for those participants, the order of the two tasks was counterbalanced. Importantly, the participants who performed both tasks did so on separate days

(i.e., delay and probability discounting tasks were never presented within the same session), separated by at least one and no more than three weeks.

All participants gave informed written consent in accordance with the Human Research Ethics Committees at York University and Baycrest Health Sciences and either received course credit (young adults) or monetary compensation (older adults) for their participation.

Procedure

Participants completed the same standard computerized delay discounting task (Kwan et al., 2013; 2015; for a review, see Green & Myerson, 2004) administered in Study 1 (henceforth, labelled as "uncued"). Over a series of trials, participants viewed pairs of monetary amounts and were asked to choose between smaller, immediate reward amounts and larger, delayed reward amounts. For each of the two delayed amounts ($100 and $2000), participants were asked to make six choices at each of seven delays (waiting 1 week, 1 month, 3 months, 6 months, 1 year, 3 years, and 10 years before receiving the reward) presented in random order.

As in the study by Kwan et al. (2015), participants also completed a second version of the delay discounting task that included personal event cues for each of the delays but was otherwise identical to the task on which they had been tested previously (henceforth, labelled as "cued"). Prior to the cued version of the task, participants were asked to identify plausible and personally specific future events that were scheduled or likely to take place for use as cues, one for each of the seven delay periods used in the delay discounting task. The participants were instructed to generate personal cues that were emotionally neutral or positive future events to avoid anticipatory anxiety or distress. To facilitate the process of generating event cues, participants were encouraged to think about and imagine different scenarios, social settings, or interactive events that they have planned or were likely to plan for themselves or with family and friends.

Participants were not specifically told that the events were likely to require money for associated expenses. If, however, the events a participant generated did not seem to involve the use of money, they were prompted to think of other events.

The cued condition proceeded in the same way as the standard, uncued condition, except that each block of choices involving a specific delay began with the corresponding temporally contiguous personal cue presented on the screen (see Figure 3.1). Upon viewing the cue, participants were given time to imagine the event in as much detail as possible. The participants then pressed a button indicating that they were ready to proceed to the first block of choice trials. The corresponding personal cue remained at the top of the screen until the end of the block to reduce memory demands and ensure that the imagined future event remained active in participants' minds.

The standard, uncued version of the task provided a baseline for measuring the effect of personal cueing and was followed 1-1.5 hours later by the cued version. During the period between the uncued and cued versions of the discounting task, participants completed other, tasks, including simple cognitive measures, questionnaires, and other behavioural tasks unrelated to the discounting tasks. In both uncued and cued conditions, the position of the immediate reward option on the screen was randomized such that it was equally likely to be presented to the left or the right of the delayed reward option. As is common in discounting research, hypothetical rewards were used. Although monetary rewards may not have the same utility for young and older adults (Seaman et al. 2016; 2018), numerous studies have shown that actual and hypothetical monetary rewards are discounted similarly (e.g., Bickel et al., 2009; Johnson & Bickel, 2002; Locey et al., 2011; Madden et al., 2003). While the repeated-measures design

raises the possibility of practice effects, studies have demonstrated the relative stability of individual discount rates over repeated testing (Harrison & McKay, 2012; Ohmura et al., 2006).

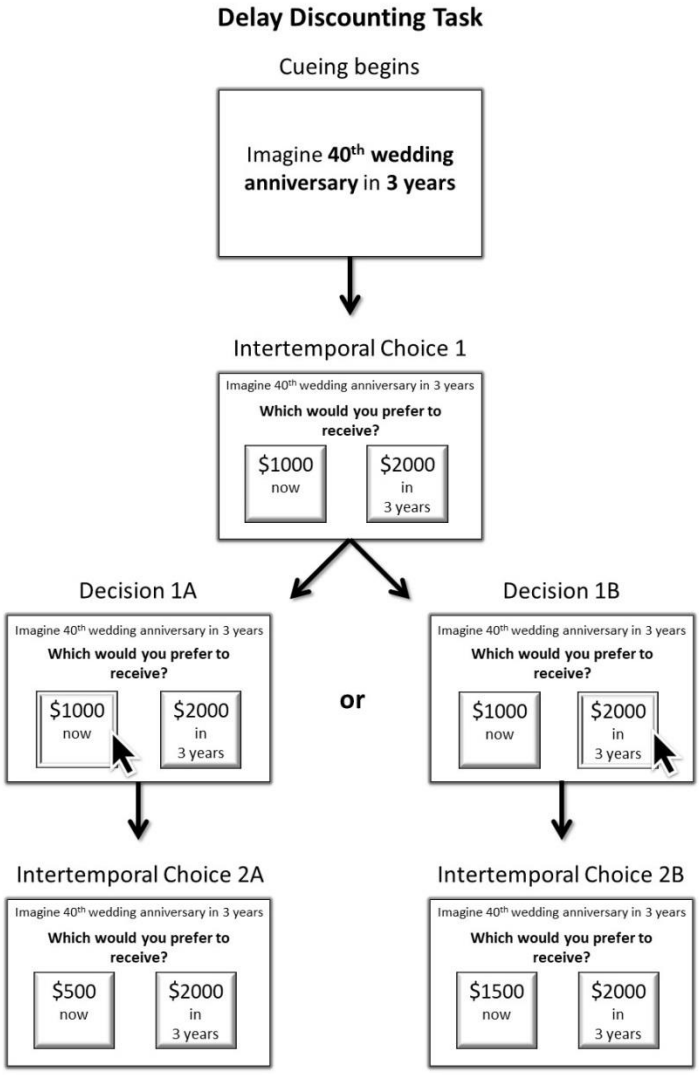

Figure 3.1. Experimental paradigms for the cued condition of the delay discounting task of Experiment 1. Participants were presented with a self-generated episodic cue and asked to imagine a personal future experience occurring at a specific delay (e.g., 3 years). They then were presented with two reward options and indicated their choice between a smaller, immediate reward and a larger reward to be received after the specified delay.

The initial 20 participants in each age group were informally asked to provide their phenomenological experiences while performing the task. To gather more systematic data regarding the mediating role played by episodic imagery across our two age groups, we asked all subsequent participants to provide phenomenological ratings of their episodic imagining following completion of the discounting tasks (Young: n = 38, 16 females, M = 20.3 years, SD = 2.29, and Older: n = 36, 20 females, M = 61.2 years, SD = 8.08). For each of the seven cues associated with the seven different delays, participants rated the frequency (*How often did this evoke an imagined experience of the future event?*), vividness (*How vivid were these imagined experiences of the future event?*), and emotionality (*How much emotion would this event make you feel?*) of their imagined experiences on a scale from one (Never or None) to five (A Lot or Highly).

Experiment 1 – Results

Figure 3.2 presents the mean subjective values of the delayed rewards for the uncued and cued conditions as a function of the delay until receipt of the reward for both young and older adults. Both young and older adults showed clear evidence of delay discounting in both cued and uncued conditions, as indicated by systematic decreases in subjective value as delay increased. For both groups and both reward amounts, cueing appeared to decrease how steeply participants discounted the delayed rewards, but young adults appeared to discount more steeply than the older adults in the uncued conditions and less steeply than the older adults in the cued conditions.

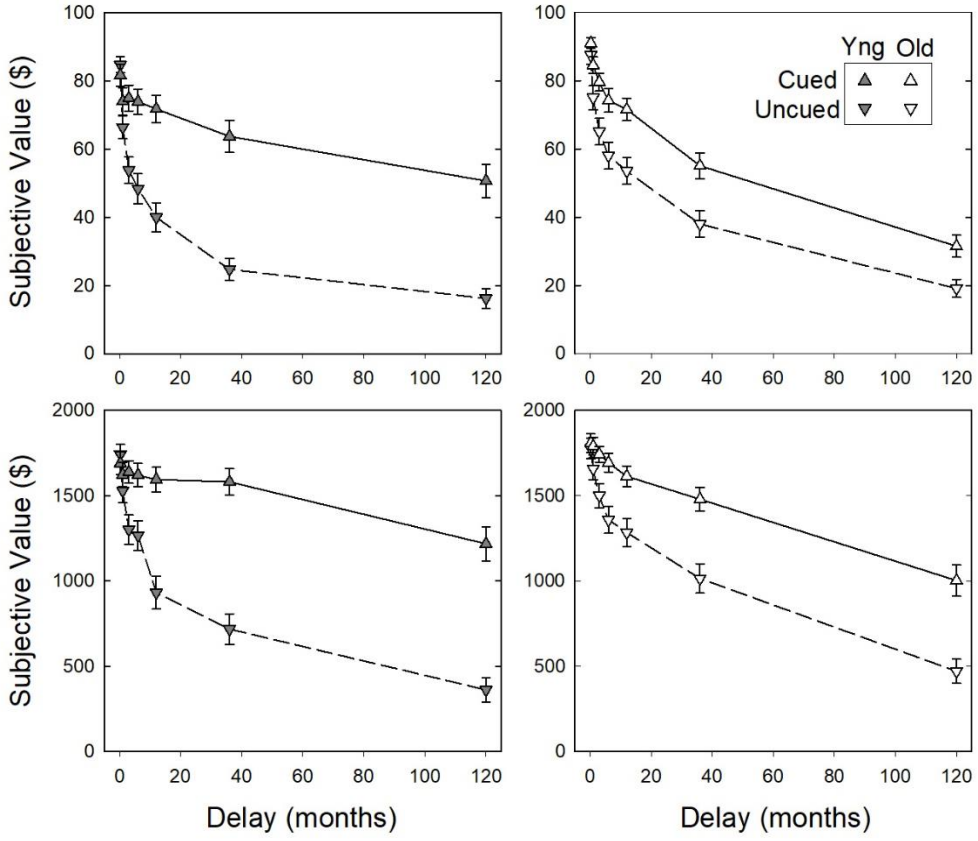

Figure 3.2. Subjective value as a function of delay. The left and right panels present the data from the young and older adult groups, respectively, and the top and bottom panels present the data from the small and large amount conditions, respectively.

Just like Study 1, the degree to which participants discounted delayed rewards was measured as the area under their empirical discounting curves (AuCs; Myerson et al., 2001). AuC values decrease as discounting becomes steeper and may range from 0.0 (maximal discounting) to 1.0 (no discounting). The AuCs for each participant in each condition (see Table 3.1) were submitted to a 2 (Age Group: Young vs. Older) x 2 (Condition: Uncued and Cued) x 2 (Reward Amount: $100 and $2000) mixed design analysis of variance (ANOVA). Significant effects of Amount and Cueing were observed: $F(1,112) = 88.50$, $\eta^2_p = .44$, and $F(1,112) =$

127.79, $\eta_p^2 = .53$, respectively, both *p*s < .001. The effect of Age was not significant, but this must be interpreted in light of the significant Age x Cueing interaction: $F(1,112) = 13.73$, $p < .001$, $\eta_p^2 = .11$, which reflects the fact that, as mentioned previously, the age difference in the uncued conditions was in the opposite direction from that in the cued conditions (see also the box plots in Figure 3.3). In addition, there was a significant Amount x Cueing interaction, reflecting the fact that the effect of cueing was greater in the Large amount condition than in the Small amount condition, as may also be seen in Figure 3.2: $F(1,112) = 6.52$, $p = .012$, $\eta_p^2 = .06$. Tests of Simple Main Effects verified that both age groups showed cueing effects (both *F*s > 38.0, both *p*s < .001) and that there was a significant Age difference in discounting in the Uncued conditions ($F = 5.75$, $p = .018$), although the Age difference in the Cued conditions (which as noted previously was in the opposite direction) failed to reach significance ($F = 3.40$, $p = .068$).

Table 3.1. Demographics and AuC values for participants in Experiment 1 (Delay Discounting)

	Young Adults	Older Adults
N	58	56
Sex (M:F)	32:26	28:28
Age in years	19.97 (2.82)	64.07 (8.58)
Uncued Condition AuCs		
Small Delayed Reward ($100)	0.25 (0.22)	0.35 (0.22)
Large Delayed Reward ($2000)	0.33 (0.28)	0.44 (0.26)
Cued Condition AuCs		
Small Delayed Reward ($100)	0.61 (0.29)	0.50 (0.21)
Large Delayed Reward ($2000)	0.73 (0.26)	0.67 (0.23)
Cueing Effect	0.38 (0.30)	0.19 (0.19)

Note: Age and Area-under-the-Curve (AuC) reported as means with standard deviations in parentheses. The cueing effect is the mean difference between the AuCs for the cued and uncued conditions, averaged across the two amount conditions.

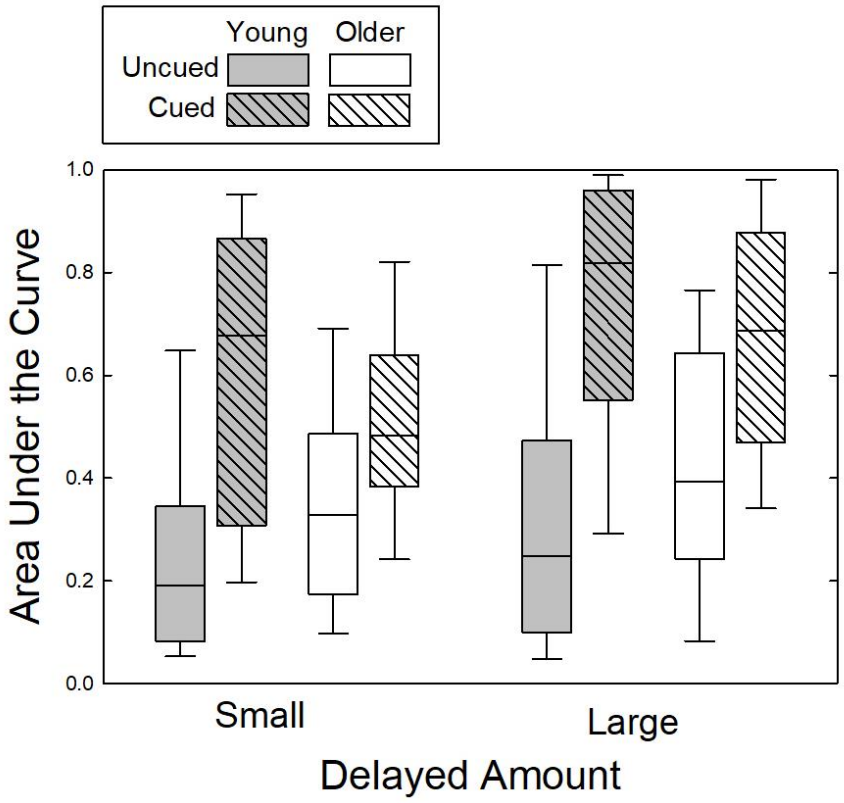

Figure 3.3. Box plots depicting the distributions of AuCs for the young and older adults in all four conditions (small and large delayed rewards in the uncued and cued conditions) of Experiment 1. The bottom and top of each box represents the 25th and 75th percentiles; the horizontal line represents the median AuC; the bottom and top whiskers extend to the 10th and 90th percentiles.

We also compared young and older adults' phenomenological ratings of the imagined experiences elicited by the episodic cues. A 2 (Age Group) x 3 (Question) mixed design ANOVA revealed a small but significant effect of Question, $F(2,144) = 9.82$, $p < .001$, $\eta_p^2 = .12$, but no effect of Age, $F(1,72) < 1.0$, $\eta_p^2 < .001$, and no Age x Question interaction, $F(2,144) = 2.65$, $p = .074$, $\eta_p^2 = .04$. Summed across the cues for the seven delays, the group mean ratings for Question 1 (frequency), Question 2 (vividness), and Question 3 (emotionality) were 26.7,

26.1, and 27.7, respectively. With respect to possible sources of the age differences in cueing effects, it should be noted that tests of simple main effects revealed no age difference on any of the three questions, all *F*s < 1.0. These findings, however, must be interpreted in light of the finding that the phenomenological ratings were not significantly correlated with the cueing effects in either age group.

Experiment 1 – Discussion

As expected, Experiment 1 replicated previous findings of reduced temporal discounting in the presence of cues to engage in episodic prospection (Benoit et al., 2011; Kwan et al., 2015; Palombo et al., 2015b; Peters & Büchel, 2010). When no cue was present, young adults discounted more steeply than older adults. Although there is no consensus in the literature on age differences in uncued discounting, the present results are consistent with previous findings by Green et al. (1994), Löckenhoff et al. (2011), and Reimers et al. (2009) of steeper discounting by young adults. Some have attributed this age difference to greater impulsivity on the part of young adults, but MacKillop et al. (2016) recently showed that the degree of discounting is unrelated to psychometric measures of impulsiveness. More importantly for current purposes, both young and older participants were more inclined to choose the larger, future reward over a smaller, immediate reward when directed to consider a personally meaningful episodic cue that was temporally contiguous with the corresponding future time period in the delay discounting task. In fact, young adults showed significantly larger cueing effects than older adults.

Examination of participants' self-reports revealed a relative lack of age-related differences in the frequency, vividness, and emotionality of imagined episodes despite the previous finding that older adults tend to generate less episodic content than young adults when asked to imagine future events or remember past experiences (Addis et al., 2008, 2010; Gaesser et al., 2011) and previous reports that episodic future thinking measures predict the degree of

delay discounting (Benoit et al., 2011; Peters & Büchel, 2009). However, there may have been limitations in our assessment of the effectiveness of the episodic cues, as evidenced by a lack of correlation between the ratings and the degree of discounting in both age groups (all *p*s > .05). These problems may be due to the fact that ratings were made after completion of the discounting task rather than during the task itself. On the other hand, obtaining phenomenological ratings concurrent with decision-making could pose its own problems because such assessment might bias participants' choices. Taken together, these considerations suggest that the focus here should remain on the significant effects of episodic cueing on intertemporal choice.

Experiment 2 – Probability Discounting

The results of Experiment 1 showed that personal, episodic cues decrease the discounting of delayed rewards in healthy adults, with young adults showing a greater cueing effect than older adults. However, it is unclear whether personally meaningful cues are themselves sufficient to positively influence financial decisions or if the decisions must be intertemporal in order for the cues to work. One way to investigate this question is to examine the effects of personal cues on a non-temporal reward discounting task. Probability discounting paradigms, in which the choice is between a smaller, guaranteed reward and a larger, uncertain reward, have been frequently used in the field of behavioural economics as a means of measuring risk-taking (e.g., Green & Myerson, 2010; Shead & Hodgins, 2009). Critically, probability discounting tasks vary the level of uncertainty, but the consequences (i.e., one either obtains a probabilistic reward or one does not) are assumed to be immediate.

Probability discounting has important properties in common with delay discounting. Both can be described with a similar, hyperboloid mathematical function (Green & Myerson, 2004).

Notably, however, delay and probability discounting are differentially sensitive to variation in both the amount (et al., 1999) and type of reward (Charlton & Fantino, 2008; Estle, Green et al., 2007). As was seen in Experiment 1, smaller delayed rewards are discounted more steeply than larger ones. In contrast, smaller probabilistic rewards are usually discounted *less* steeply than larger ones. Individual differences suggest that delay and probability discounting reflect different traits as well as involve different neural mechanisms and cognitive processes (e.g., Myerson et al., 2003; Seaman et al., 2018; Peters & Büchel, 2009; for a review, see Green & Myerson, 2013). As such, one cannot necessarily predict whether effects seen with a different task, delay discounting, with which it shares some but not all processes, will also be observed with probability discounting. Although older adults are often considered to be more risk-averse than younger adults, a recent meta-analysis of experiments on age differences in risky choice suggests that age-differences may predominantly reflect differences in learning the outcome probabilities, rather than differences in the choice process itself (Mata et al., 2011). Because participants in probability discounting tasks usually are provided the relevant probabilities, we predict no age-related differences in the uncued conditions of our probability discounting.

Moreover, despite the clear findings with respect to age-related differences in the effects of cueing on delay discounting observed in Experiment 1, it remains an empirical question whether young and older adults' probability discounting will be affected to the same degree by personal cues due to the behavioural dissociations of delay and probability discounting noted above. Indeed, it also is an empirical question whether age-related changes across both groups will be affected by cueing at all. Both these questions are the focus of Experiment 2.

Experiment 2 – Methods

Participants

To evaluate the effects of personal cues on risky decision-making, 38 young and 36 older adults (a subset of the participants in Experiment 1) completed uncued and cued version of a probability discounting task previously used in a study of individuals with hippocampal amnesia and healthy controls (Kwan et al., 2012; 2013). According to Cohen (1988), these sample sizes provide more than adequate power (>.80 with $\alpha = .05$) to detect cueing effects of the sizes observed with delay discounting in Experiment 1 ($d \geq 1.0$). Again, no sex differences were observed for either age groups (ps > .05). As noted in Experiment 1, administration of the delay and probability discounting tasks was separated by one to three weeks and their order was counterbalanced. At the end of their second session, participants also completed the Barratt Impulsiveness Scale (BIS-11; Patton, Stanford, & Barratt, 1995). The BIS-11 is a 30-item self-report instrument that is widely used to assess the construct of impulsivity. All participants' scores were between 52 and 71, which are thought of as the normal range for impulsiveness (see Stanford et al., 2009, for a review).

Procedure

Participants completed the same standard computerized probability discounting task administered in Study 1 (henceforth, labelled as "uncued"). Over a series of trials, participants were presented with pairs of hypothetical monetary amounts on a computer screen and asked to make choices between a smaller, certain reward and a larger, probabilistic reward. For each of two probabilistic amounts ($250 and $2000), participants were asked to make six choices at each of six probabilities (90%, 75%, 50%, 20%, 10%, and 5% chance of receiving the reward) presented in random order.

Following the standard, uncued condition, the participants completed a probability discounting task in which the choices were accompanied by personally meaningful event cues (henceforth, labelled as "cued"). Prior to the cued condition, which followed the same procedures as the uncued probability discounting condition, the participants were asked to identify six specific, personally meaningful events that they believed were plausible. The participants were told to envision activities or events that, unlike the events in the previous experiment, were not tied to a specific place or time, just as the possible rewards in the probability discounting task were not associated with a specific place or time. To facilitate the process of generating event cues, participants were encouraged to think about and imagine different scenarios, social settings, or interactive events they have considered engaging in or attending, either by themselves or with family and friends. As in Experiment 1, participants were asked to generate only emotionally neutral or positive events so as to avoid anticipatory distress. Again, participants were not specifically informed that the events that were to be identified for the study were ones that required money. If, however, the generated events did not seem to involve the use of money, then participants were prompted to think of other events, and only cues that suggested money would be needed for the associated event were used.

The cued version of the probability discounting task proceeded in the same way as the uncued version, except that each block of choice trials began with one of the six personal cues, which had been randomly assigned to the six probabilities. Upon viewing the cue, participants were given time to imagine the event in as much detail as possible. Participants then pressed a button indicating that they were ready to proceed to the first block of the task. The personal cue remained at the top of the screen until the end of the block to reduce memory demands and ensure that the event remained active in the participants' minds (see Figure 3.4).

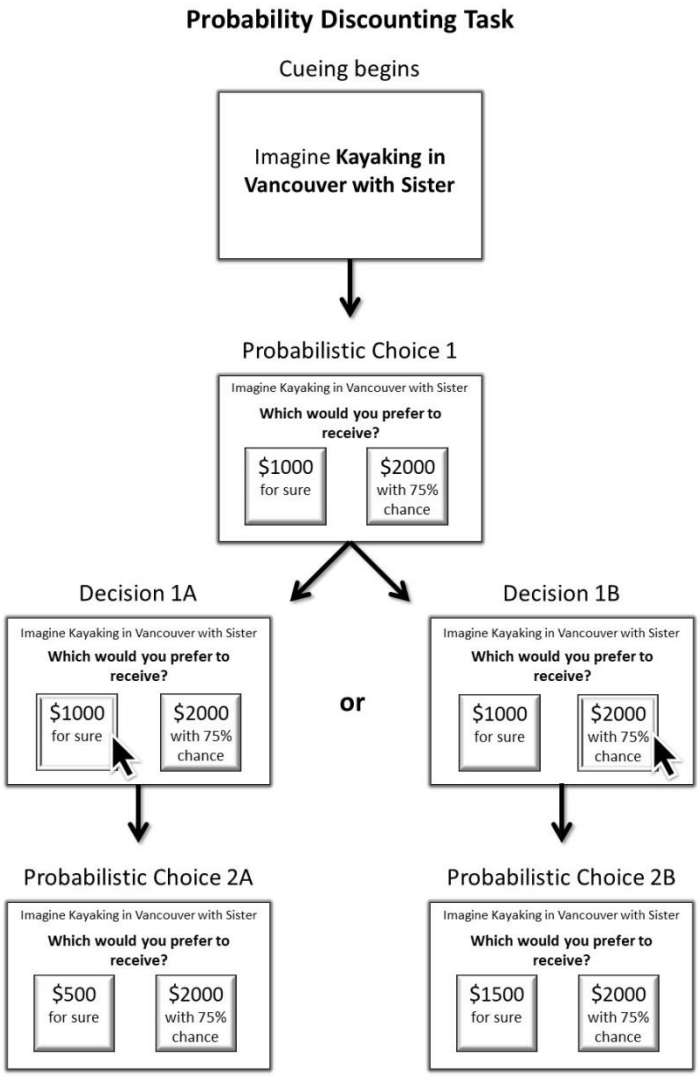

Figure 3.4. Experimental paradigms for the cued condition of the probability discounting task of Experiment 2. Participants were presented with a self-generated personal cue and asked to imagine a personal experience that was not time specific. They then were presented with two reward options and indicated their choice between a smaller, certain reward and a larger reward that had a specified likelihood of being received.

As in Experiment 1, the standard, uncued version of the discounting task was completed approximately 1.0-1.5 hours prior to the cued version as a baseline for measuring the effect of

personal cueing and to ensure that any benefits from cueing did not influence the baseline discounting rates. Again, the tasks within the session included simple cognitive measures, questionnaires, and other behavioural tasks that were unrelated to the discounting tasks participants completed. To minimize potential carryover effects from the delay discounting task to the probability discounting task, different and unrelated cues were selected for the delay and probability discounting tasks. Following completion of both the uncued and cued versions of the probability discounting tasks, participants rated the experiences elicited by the cues on scales from one to five using the same three questions as in Experiment 1.

Experiment 2 – Results

Figure 3.5 presents the mean subjective values of the probabilistic rewards for the uncued and cued conditions as a function of the odds against receiving those rewards (i.e., $(1 - p)/p$, where p is the probability of receiving the reward). As may be seen, both young and older adults showed clear evidence of probability discounting in both cued and uncued conditions, as indicated by systematic decreases in subjective value as the odds against increased.

The AuCs for each participant in each condition (see Table 3.2) were submitted to a 2 (Age Group: Young vs. Older) x 2 (Condition: Uncued and Cued) x 2 (Reward Amount: $250 and $2000) mixed design ANOVA. There was a significant effect of Amount, reflecting the fact that, as expected, the larger reward amount was discounted more steeply than the smaller amount: $F(1,72) = 24.16$, $p < .001$, $\eta_p^2 = .25$. Importantly, however, neither the effect of Condition nor the effect of Age were significant, $F(1,72) = 1.92$, $p = .17$, $\eta_p^2 = .03$, and $F(1,72) < 1.0$, $p = .96$, $\eta_p^2 < .001$, respectively, nor were any of the interactions, all Fs < 1.0. Box plots of the distribution of AuCs in each condition are shown in Figure 3.6.

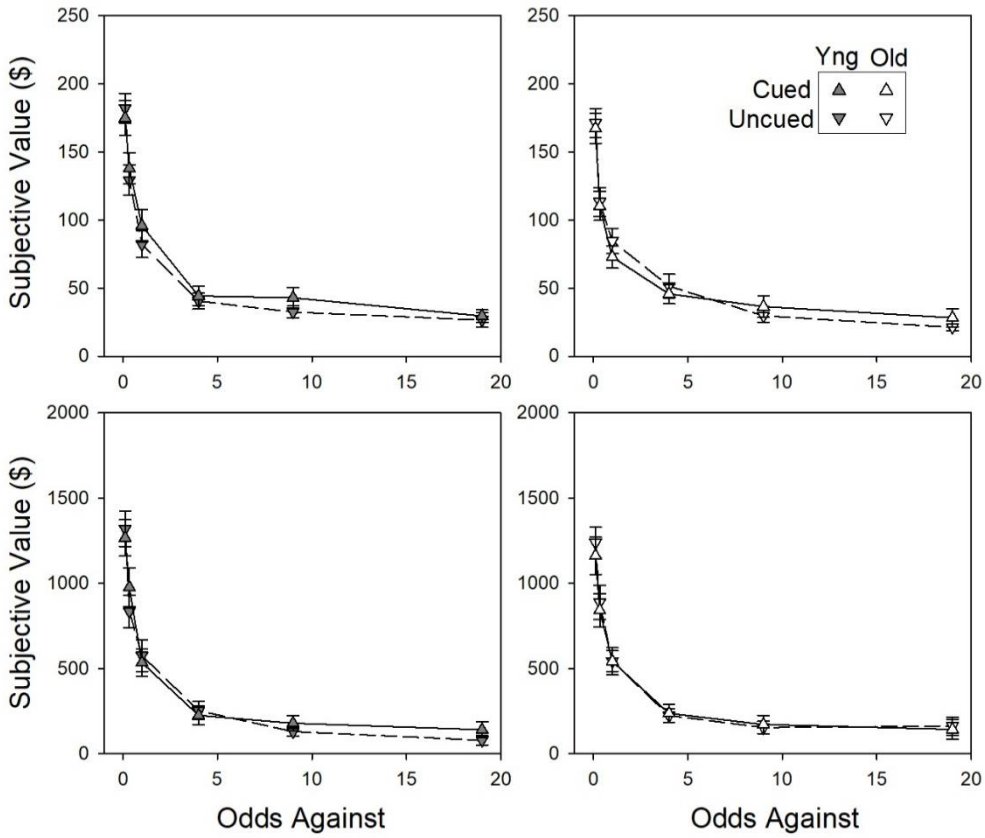

Figure 3.5. Subjective value as a function of the odds against receiving a probabilistic reward. The left and right panels present the data from the young and older adult groups, respectively, and the top and bottom panels present the data from the small and large amount conditions, respectively.

Table 3.2. Demographics and AuC values for participants in Experiment 2 (Probability Discounting)

	Young Adults	Older Adults
N	38	36
Sex (M:F)	22:16	16:20
Age in years	20.26 (2.29)	61.19 (8.08)
Uncued Condition AuCs		
Small Delayed Reward ($250)	0.16 (0.09)	0.16 (0.11)
Large Delayed Reward ($2000)	0.10 (0.08)	0.11 (0.09)
Cued Condition AuCs		
Small Delayed Reward ($250)	0.19 (0.13)	0.17 (0.14)

Large Delayed Reward ($2000)	0.12 (0.12)	0.13 (0.15)
Cueing Effect	0.02 (0.08)	0.01 (0.11)

Note: Age and Area-under-the-Curve (AuC) reported as means with standard deviations in parentheses. The cueing effect is the mean difference between the AuCs for the cued and uncued conditions, averaged across the two amount conditions.

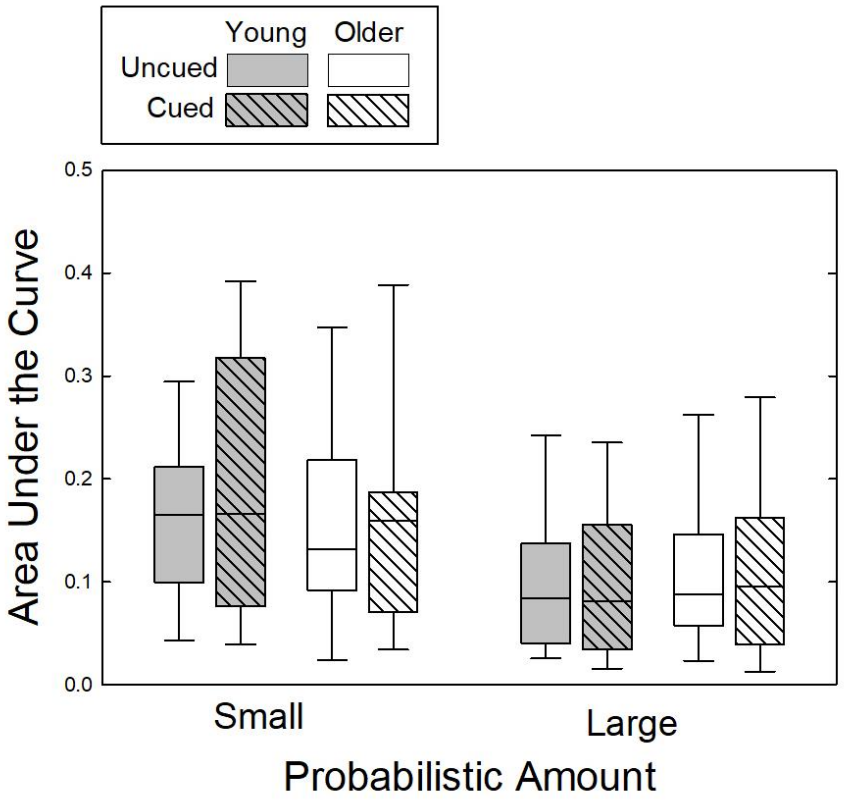

Figure 3.6. Box plots depicting the distributions of AuCs for the young and older adults in all four conditions (small and large probabilistic rewards in the uncued and cued conditions) of Experiment 2. The bottom and top of each box represents the 25th and 75th percentiles; the horizontal line represents the median AuC; the bottom and top whiskers extend to the 10th and 90th percentiles.

Although the ANOVA failed to reveal a significant difference between the cued and uncued probability discounting conditions (i.e., we failed to reject the null hypothesis), a limitation of classical statistical analyses like ANOVA is that it does not directly assess the evidence *for* the null hypothesis, which in this case is that there is no effect of cueing on probability discounting. We therefore used a Bayesian approach, which unlike classical null hypothesis significance testing, can directly compare the evidence for the null hypothesis with the evidence for the alternative hypothesis (i.e., there is an effect of cueing, Quintana & Williams, 2018). Bayesian paired samples *t*-tests were conducted on the cueing effects from both the young and older adults using JASP software. For the small reward amount in both the uncued and cued conditions, the Bayes factor was 0.269; for the large reward amount conditions, the Bayes factor was 0.222. These values, which compare the likelihood of the alternative hypothesis given the present data to the likelihood of the null hypothesis given the data, represent what Jeffreys (1961) termed substantial evidence for the null. They may be contrasted with the Bayes factors for the cueing effects in Experiment 1 that represent compelling evidence for the alternative hypothesis and against the null (both Bayes Factors > 150).

Finally, we compared the phenomenological ratings of the imagined experiences elicited by the personal cues. A 2 (Age Group) x 3 (Question) mixed design ANOVA failed to reveal effects of either Question or Age, both *F*s < 1.0, although there was a significant Age x Question interaction: $F(2,144) = 7.\ 14$, $p = .001$, $\eta_p^2 = .09$. The source of this interaction appeared to be in the different patterns of mean ratings, which in the young adults were highest for Question 1 and lowest for Question 3 (23.3 vs. 21.2, respectively) but showed the reverse pattern in the older adults (21.9 vs. 23.1, respectively). It should be noted, however, that tests for simple main effects failed to reveal a significant age difference on any question (all *F*s < 2.9, all *p*s > .09). As was

the case in Experiment 1, the phenomenological ratings were not significantly correlated with the cueing effects in either age group, again suggesting problems with the assessment of cue effectiveness after completion of the discounting task. This remains an interesting issue, but one that will have to be addressed in future studies.

Experiment 2 – Discussion

The primary research question in this experiment was whether personally meaningful cues, which were found to modulate the degree of delay discounting in Experiment 1 and previous studies, would similarly modulate other forms of decision-making. Specifically, the experiment examined whether such cues would affect choices on a (non-temporal) probability discounting task. Consistent with previous studies of uncued probability discounting, smaller probabilistic rewards were discounted less steeply than larger ones, the opposite of the amount effects observed with delay discounting (Experiment 1; for a review, see Green & Myerson, 2004), and no age differences were observed (Seaman et al., 2016; Seaman et al., 2018). More importantly, there were no differences observed in either young or older adults' probability discounting rates when they were cued to think about specific personal experiences and their discounting rates when they were not cued. Not only did the effect of cueing fail to reach statistical significance, but Bayesian analysis provided very compelling evidence for the null hypothesis that there was no cueing effect in decisions involving probability discounting.

General Discussion

The two experiments compared the effects of personally relevant cues associated with delayed rewards (Experiment 1) and probabilistic rewards (Experiment 2) on rate of discounting in young and older adults. In uncued conditions, older adults discounted delayed rewards less steeply than young adults, consistent with several previous studies (e.g., Green et al., 1994;

Löckenhoff et al., 2011; Reimers et al., 2009), and hopefully contributing to a resolution of the controversy concerning this issue (e.g., Chao et al., 2009; Read & Read, 2004). As will be seen, the observed shallower delay discounting of older adults has important implications for interpretation of the age difference in cueing effects. In contrast to the results for uncued delay discounting, no age differences were observed in uncued probability discounting, also consistent with previous findings (Seaman et al., 2016; 2018).

With respect to the effects of cueing on delay and probability discounting, which were the focus of the present study, it is well-established that young adults discount delayed rewards less when presented with cues to imagine future events (e.g., Benoit et al., 2011; Peters & Büchel, 2010), but few studies have investigated whether such cues can have similar effects in older adults (Kwan et al., 2015; Palombo et al., 2015b; Sasse et al., 2017). Such effects might not be observed because older adults generally tend to generate fewer episodic details of imagined future events compared to young adults (Addis et al., 2008; Schacter et al., 2013). In fact, Sasse et al. (2017) did not find an effect of event cues in an older adult sample. The results of Experiment 1 revealed that older adults can, indeed, show episodic cueing effects on delay discounting, although they also revealed that these effects were smaller than those observed in young adults. Experiment 2 examined whether the discounting of probabilistic rewards would also be affected by event cues and, if so, whether there are age-related differences in this effect. Notably, the present results provide clear evidence that although both young and older adults steeply discounted the value of probabilistic rewards, personally relevant event cues failed to modulate the degree of probability discounting in either age group (see Figure 3.7).

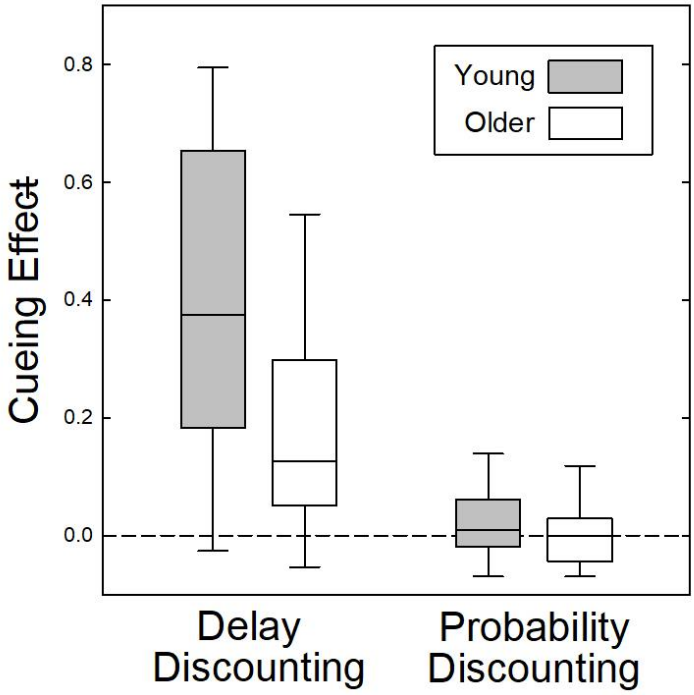

Figure 3.7. Box plots depicting the distributions of cueing effects (calculated as the difference between the AuC for the cued and uncued conditions) for the young and older adults in Experiment 1 (delay discounting) and Experiment 2 (probability discounting). The horizontal dashed line represents no difference between the AuCs in the cued and uncued conditions, indicating no effect of episodic cueing.

Cueing and the discounting of delayed rewards

In Experiment 1, as expected, personally relevant event cues increased the tendency of the young participants to choose larger, future rewards over immediate, smaller gains. More specifically, young adults showed shallower discounting of future rewards when presented with cues related to personally meaningful events occurring around the same time as the delayed rewards relative to the discounting observed in the absence of such cues. Importantly, older adults were similarly affected by episodic cues but to a lesser extent.

As noted above, Sasse et al. (2017) reported that episodic cues did not reduce delay discounting in their older adult sample, and they suggested that older adults are less able to benefit from episodic cueing than younger adults due to differences in cognitive control. It should be noted that there are several methodological differences between the current study and that by Sasse and colleagues. In their study, participants in the episodic imagining conditions were asked to imagine spending time at a café, either with someone they knew or in order to conduct a media interview with a famous individual. Although in a previous study, Sasse et al. (2015) found that young adults' cueing effects did not depend on the nature of the cues provided, it is possible that, in fact, older adults are sensitive to the nature of episodic cues, and this could account for the difference in results. Perhaps the more important point, however, is that in both Sasse et al. (2017) and Experiment 1 of the present study, older adults' delay discounting was significantly less affected by episodic cues than that of young adults.

The finding that episodic cueing led to a larger reduction in the degree of discounting in young adults than in older adults, while consistent with the finding that older adults generate fewer episodic details than young adults when imagining future events (Addis et al., 2008; Lapp & Spaniol, 2017; for a review see Schacter et al., 2013), raises additional questions as to the basis for these age-related differences. Construal Level Theory (Trope & Liberman, 2010) posits that temporally distant events are perceived more abstractly and in less detail than more temporally proximal events and that this is responsible, at least in part, for people preferring sooner rewards, whose representations are more concrete even when they are smaller than delayed rewards, which may be more abstractly conceived (Kim et al., 2013). Because personally meaningful cues can produce more concrete and detailed representations of future rewards, such cues could lead to reduced delay discounting. Indeed, older adults tend to report

more ‘generic’ memories with fewer specific details and show reduced episodic future imagining (Addis et al., 2008; Rubin & Umanath, 2015). Further, the established age-related differences in event memory and future imagining could account for the smaller cueing effects observed in older adults, but this interpretation will have to be reconciled by the finding that in the uncued conditions of Experiment 1, the older adults showed shallower discounting than younger adults (see also Green et al., 1994; Löckenhoff et al., 2011; Reimers et al., 2009).

The results of neurocognitive studies suggest an alternative approach to explaining the decreased effect of episodic cues on older adults’ delay discounting. Older adults show lower activation of both their MTL and vmPFC than young adults when imagining future events (Addis et al., 2007; Buckner & Carroll, 2007), and there is evidence that age-related changes to the hippocampus may lead to the decreased ability to access specific events in both remembering and future imagining (Gaesser et al., 2011; Schacter et al., 2013). In addition, older adults’ reduced event detail fluency may not only be specific to MTL episodic memory changes but also reflect age-related changes to frontal lobe structures (see Cabeza & Dennis, 2013; Raz, 2004 for reviews). Either or both of these neural changes may contribute to age-related declines in the ability to imagine future events, leading to a decreased ability to benefit from episodic cues like that observed in Experiment 1; however, this interpretation, like that of Construal Level Theory, would need to be reconciled with older adults’ shallower discounting of delayed rewards in the uncued conditions.

Part of the appeal of the Temporal Construal Theory and neurocognitive accounts just described is that they have implications for both uncued and cued discounting. It is also possible, however, that different processes are involved in these two situations and, indeed, both accounts have problems explaining the different patterns of age-related differences observed in the uncued

and cued conditions of the present study. In previous studies, our group showed that individuals with MTL damage and deficits in episodic imagining discount delayed rewards to the same degree as healthy controls despite these deficits (Kwan et al., 2012; 2013). Although the delay discounting of individuals with MTL damage does differ from controls under some circumstances, studies by Kwan and colleagues established that episodic future thinking need not always be involved in delay discounting, particularly in the absence of episodic cues, and inferred that MTL patients could use a semantic, rather than episodic, strategy for future thinking in evaluating delayed outcomes. Semantic, unlike episodic, cognitive functions are relatively preserved in older adults (e.g., Devitt et al., 2017; Levine et al., 2002). If such functions predominate in the absence of specific episodic cues, this could explain why older adults do not show steeper discounting than young adults in the present study, though it would not explain why older adults show shallower discounting. Age-related decreases in cognitive control (Sasse et al., 2017) can also be ruled out as the explanation for the present results because such decreases predict steeper uncued discounting by older adults.

An important finding in Experiment 1 of the current study is that older adults showed smaller cueing effects than young adults. However, this finding should be considered in the context of differences between the age groups in the uncued condition, in which older adults showed shallower delay discounting. It is possible that the effect of cues on older adults' discounting is less pronounced than the effect on young adults' discounting because the subjective value of a delayed reward to older adults has less room to increase. Although this possibility cannot be ruled out, it is equally important to understand the significant difference in uncued discounting between young and older adults (e.g., Green & Myerson, 1994; cf Read & Read, 2004; see Green et al., 1996, for discussion of how socioeconomic differences may

contribute to such discrepant findings). Another possibility is that the relative shallowness of uncued discounting in older adults can be understood through a social cognitive lens For example, a recent review investigated the relation between the perception of one's identity when faced with a pending life transition (e.g., graduation, retirement, death) and how this perception, in turn, drives behaviour (Moss & Wilson, 2018). The authors concluded that when one perceives their identity as enduring throughout (rather than ending at) the transition, they are motivated to act responsibly and to delay gratification. Moss and Wilson (2018) further reported that older adults tend to exhibit such identity continuity, whereas younger adults more often perceive their identities as discontinuous at a transition point and are therefore motivated to act impulsively. Thus, there are numerous demographic, cognitive, and affective differences between young and older adults (e.g., age-related differences in affective responses to future outcomes and to the decision-making process itself; Löckenhoff et al., 2011; for reviews, see Ferraro & George, 2015; Schaie & Willis, 2016), and their roles in delay discounting will require further study (see Sparrow & Spaniol, 2016 for a brief review related to this topic).

Cueing and the discounting of probabilistic rewards

Given the effects of episodic cueing on delay discounting in both young and older adults, the question arises whether personally relevant cues also affect other types of decision-making tasks, particularly ones that do not directly involve a substantial delay, and whether similar age differences are observed on both delay and probability discounting tasks. Accordingly, Experiment 2 examined the effects of personal cues on probability discounting in young and older adults. It should be noted, of course, that in probability discounting, the decisions may also involve anticipating the future. For example, people may ask themselves what it would be like to actually receive (or not receive) the probabilistic reward. In fact, such imaginings provide the

basis for theories of risky choice in which decisions are based on anticipated regret (e.g., Loomes & Sugden, 1982), though a previous study of risky choice in a case of pronounced episodic amnesia (Craver et al., 2014), raises questions about the role of future thinking in risky choice. Despite the fact that episodic and semantic future imagining could play a role in probability discounting, cueing did not affect the choices of participants in either age group in Experiment 2, which is in sharp contrast to the results of Experiment 1 where episodic cueing substantially decreased the degree of delay discounting.

The difference in the effects of cueing on delay and probability discounting could reflect the differences in brain activity observed during intertemporal choice and risky decision-making. Despite a common system featuring the ventral striatum and the orbitofrontal cortex that may be involved in both delay and probability discounting, Peters and Büchel (2009) also described separate neural processes that could point to a dissociation in the decision-making mechanisms involved in intertemporal and risky choice. Probability discounting activated the superior parietal cortex and middle occipital areas. Delay discounting, in contrast, activated the frontal pole and subregions of the posterior cingulate cortex, leading Peters and Büchel (2009) to assign these regions a specific role in coding for value in the context of delays. Relatedly, these areas, along with the hippocampus and vmPFC, have been identified as central to episodic future thought and event construction (Addis et al., 2007; Schacter & Addis, 2009; Peters & Büchel, 2010; Szpunar et al., 2007).

Further evidence for the view that different mechanisms are involved in intertemporal and risky choice comes from a study by Bulley et al. (2019), in which young adult participants imagined future events based on positively or negatively valenced word cues prior to completing a delay discounting task and a risk-taking task. Their manipulation of event cues, which were

valence-based but not personally meaningful like the cues generated in the current study, showed that both positive and negative episodic cues decreased discounting of delayed rewards but had no effect on risk taking, although, as noted above, the fact that the BART involves probabilistic losses as well as gains limits direct comparison with the discounting of delayed rewards.

A possible exception to the present findings comes from a novel study by Kaplan et al. (2016). Participants were cued by viewing age-morphed representations of themselves prior to rating the likelihood that they would give up a hobby if there was a chance that quitting would increase the likelihood of the participants being healthy or unhealthy in 30 years. As in a standard, uncued probability discounting task, the probability of these health consequences was varied. If the future health consequences of the hobby would be positive (albeit probabilistic), participants were more likely to continue their hobby when shown an age-morphed representation (probability discounting was shallower), whereas if the consequences would be negative, they were more likely to quit (probability discounting was steeper). The fact that cueing effects were observed on this modified probability discounting task might appear inconsistent with the present findings; however, the sample sizes in their two experiments were extremely small (*N*s of 5 and 6, respectively). Importantly, the choice consequences (better or worse health) would occur years in the future, and thus the observed cueing effects may still have been due to the fact that it was delayed events that were being imagined.

Taken together, the results of the two present experiments suggest personally relevant cues primarily influence decision-making processes that involve evaluating the duration of waiting involved in choice outcomes, consistent with the view that intertemporal choice and risk-taking decisions involve separate neural mechanisms and cognitive processes (Green & Myerson, 2004; 2013).

Do different types of discounting reflect different 'impulsivity' constructs?

The present findings have implications for understanding the relation between intertemporal choice, as exemplified by the delay discounting task in Experiment 1, and risky decision-making, as exemplified by the probability discounting task in Experiment 2. These two discounting tasks were constructed to be directly analogous to one another so they might better reveal similarities and differences between these forms of choice behaviour (Green & Myerson, 2004). Early behavioural economic accounts often presumed that one process underlies both forms of discounting, although researchers have disagreed about which form is fundamental (Green & Myerson, 1996; Kagel, Green, & Caraco, 1986; Rachlin et al., 1991). After all, the longer the wait for a delayed reward, the greater the risk of not receiving it, and the lower the probability that one will receive a reward playing a slot machine, for example, the longer one will likely have to play before winning. Moreover, the iconic example of an impulsive person is a substance abuser, who is typically both a risk taker and someone who often chooses short-term rewards with blunted regard for long-term outcomes.

If both an inability to delay gratification and risk-taking were manifestations of a single 'impulsivity' construct, however, then in the context of discounting, impulsive individuals would show steeper delay discounting (suggesting greater sensitivity to delay) and shallower probabilistic discounting (indicating lower sensitivity to probability). Contrary to this expectation, however, analyses based on individual young and older adults' AuCs in the uncued conditions of the present two experiments revealed that delay and probability discounting were not significantly correlated for either small or large rewards (all *p*s >.27). The hypothesis of a single impulsivity construct also predicts that analogous manipulations will have the same effects on both delay and probability discounting, but smaller delayed rewards were discounted more

steeply than larger ones in Experiment 1, whereas smaller probabilistic rewards were discounted less steeply than larger ones in Experiment 2.

Both the lack of correlation between delay and probability discounting and the opposite effects of amount are consistent with previous results (for reviews, see Green & Myerson, 2010; Green et al., 2014). The present finding that event cueing strongly affects delay discounting (Experiment 1) but has no effect on probability discounting (Experiment 2) in either young or older adults further strengthens the argument against a single impulsivity construct, suggesting instead that different traits underlie these two kinds of discounting (Green & Myerson, 2013).

Conclusions

The primary issues in the present study are whether providing personal cues to imagine specific events during which money would be useful decreases the extent to which young and older adults discount delayed and probabilistic rewards and, if so, whether they do so to a different extent. Previous studies have observed age-related differences in the ability to engage in future-oriented thought, leading to the expectation that older adults would be less affected by event cueing, but the effect of similar, personally relevant event cueing on probabilistic rewards has received little previous study. Older adults are of special interest here because they are a population often faced with episodic memory deficits and, ostensibly, parallel deficits in episodic imagining changes (Addis et al., 2008, 2010; Gaesser et al., 2011). Because the cueing effect is assumed to result from imagining the cued events, one thus might expect that older adults would show smaller effects or might even be unaffected by such cues.

Many behavioural problems covary with the degree of discounting (Madden & Bickel, 2010), with substance abuse, which may increasingly occur with older adults (e.g., Chhatre et al., 2017; Han et al., 2017), being the iconic example. Accordingly, much behavioral economic

research is currently investigating interventions that might reduce the rate of discounting, with episodic future thinking being a major focus of such investigations (for a recent review, see Rung & Madden, 2018). Episodic future thinking techniques typically involve generating and then responding to episodic cues presented at the time when decisions are made, similar to the procedures used in the present study. If older adults are less affected by such manipulations, then episodic future thinking would be less likely to provide an alternative route or intervention to sustain typical decision-making in this population. Although, as predicted, older adults in the present study showed smaller cueing effects than young adults, episodic cues did significantly decrease older adults' discounting of delayed rewards, and therefore, we are hopeful regarding the prospects for successful use of episodic or personally relevant event cueing as an intervention to improve decision-making in this population.

Finally, we identify that a major concern with older adults is potential vulnerability to scams and problems with financial decision-making, which are perhaps more related to problematic risk-taking than with delay of gratification. Although we observed no effect of cueing on either young or older adults' probability discounting in the present study, we also observed no age differences in uncued discounting. A previous study of cueing and probability discounting in young adults did report significant effects, although notably the probabilistic outcomes in that study were years in the future (Kaplan et al., 2016). This finding suggests a wider role for cueing, one that applies whenever future events are involved, regardless of whether they are probabilistic and delayed or simply delayed, raising the possibility of a broader applicability of interventions using episodic cueing techniques. It remains to be seen whether this expanded view of cueing's role will be confirmed in future studies, particularly those with older

adults. If so, it could have both theoretical and applied implications for how competent and autonomous decision-making can be sustained by adults of all ages.

Adapted from:

Mok, J. N. Y., Kwan, D., Green, L., Myerson, J., Craver, C. F., & Rosenbaum, R. S. (2020). Is it time? Episodic imagining and the discounting of delayed and probabilistic rewards in young and older adults. *Cognition, 199*, 104222. https://doi .org/10.1016/j.cognition.2020.104222

CHAPTER 4

Study 3: Evaluating probability discounting with and without episodic cues following lesions to the vmPFC and MTL

Findings from the previous study indicate that episodic event cues have little to no effect on probability discounting in neurotypical young and older adults. However, it remains to be seen whether event cues can modulate probability discounting in clinical populations who have shown impaired probabilistic reward valuation. As we found in Study 1 of this dissertation, individuals with brain lesions to the vmPFC show atypical shallow discounting for delayed rewards and, conversely, steeper discounting for probabilistic choices. Evidence that delay and probability discounting are only weakly related (Holt et al., 2003) and respond in opposite ways to reward amount manipulations (Green & Myerson, 2004), as observed in Study 1, suggests that they are more likely to reflect separate processes (Myerson et al., 2003; see Green & Myerson, 2013 for review). Nevertheless, decision theories have proposed that these types of choices rely on similar methods of subjective valuation, allowing us to normalize how we situate future-oriented and risky rewards on simple scaling systems (Kable & Glimcher, 2009; 2010). For example, a large body of research has shown that subjective valuation of rewards can be readily increased by considering personally meaningful experiences prior to the onset of decisions involving delays (Rung & Madden, 2018, 2019; see Kurth-Nelson et al., 2012, for a theoretical model).

Another way that the reward valuation of delay and probability discounting has been described in the literature is that both could be governed by the uncertainty of future outcomes. The anticipatory regret literature suggests that rewards that are obtained after longer delays are perceived as less certain (Logue, 1988; Rotter, 1954), while a series of probabilistic rewards can be experienced as a series of delayed rewards (Rachlin et al., 1991). These examples appear to

point towards a shared function of episodic future thinking in delay and probability discounting. If vmPFC function is necessary to both delay and probability discounting due to its role in subjective valuation of rewards, then increasing subjective value with personal cues should influence both delay and probability discounting. Whether this is the case, and how this plays out at a neurocognitive level, is unclear and is the focus of the current patient-lesion study.

As stated earlier, Boyer (2008) suggested that the simulation of episodic prospection allows us to consider immediate consequences and to make future outcomes materialize and become more concrete (see also O'Donnell et al., 2017; Thorstad & Wolff, 2018). Findings from neuroimaging and lesion studies have demonstrated that episodic memory may be involved in the process of simulating hypothetical episodes about the self across time, allowing us to plan and make decisions about the future (Addis, 2020; Addis et al., 2007). In a seminal study by Peters & Büchel (2010), healthy adult participants who were tasked with imagining personal event cues showed a reduction of temporal discounting of future rewards by choosing the more uncertain larger gains in lieu of the presumably more salient reward choice (see also Benoit et al., 2011). Importantly, the findings of a modulatory effect on reward discounting through episodic cueing also described a functional coupling of the medial prefrontal regions (including vmPFC) and the hippocampus/MTL with the activation of a "future thinking" network including the retrosplenial cortex and left lateral parietal cortex (Addis et al., 2007; Szpunar et al., 2007) and regions of the brain implicated in decision-making and control of choice behaviour (e.g., anterior cingulate cortex; Brown & Alexander, 2017). This finding affirmed the relationship between these two brain areas in episodic imagining and future thinking, extending it to decision-making. Indeed, coupling of these regions during episodic imagining indicated a

coordinated effort of episodic memory and goal-directed systems to process future payoffs and choices (Bar, 2010; Buckner & Carroll, 2007; Peters & Büchel, 2010; Schacter & Addis, 2009).

The contributions of the vmPFC and MTL to an array of cognitive functions has been well-documented through the patient-lesion method (McCormick et al., 2018). The vmPFC has been described as the mediator for a domain-general reward valuation system (Blankenstein et al., 2017; Engelmann & Tamir, 2009; Seaman et al., 2018) and a number of studies have shown that the vmPFC may be called upon during decision-making to provide values to multiple attributes that are then integrated to generate the most optimal choice (Kahnt et al., 2011; Vaidya et al., 2018). In patient-lesion models, damage to the vmPFC is said to affect retrieval of schematic knowledge regarding different attributes of a situation or choice, thus impairing optimal judgements in naturalistic settings or on realistic decision-making tasks (Peters & D'Esposito, 2016; Spalding et al., 2015). A study by Sellitto et al., (2010) was one of the first to confirm that damage to the vmPFC led to steeper discounting across different reward types, possibly due to disruptions in forming vivid episodic details that enhance thoughts about the future and reward imagery at the time of choice or bolster the considerations of reward choice preferences (see also Peters & D'Esposito, 2016, 2020). Unlike vmPFC patients, delay discounting in MTL-lesioned patients has been found to be similar to that of matched healthy controls (Kwan et al., 2012, 2013) and is without the extreme bias towards smaller immediate rewards that is observed in individuals with frontal deficits (Ciaramelli, De Luca, et al., in press; Sellitto et al., 2010).

One common feature in patients with lesions to the vmPFC and MTL is impaired episodic memory and future thinking. Difficulties engaging in the retrieval of episodic details to facilitate economic decision-making for MTL patients are in line with extensive work suggesting

impoverished foresight in envisioning future outcomes (Race et al., 2011; Rosenbaum et al., 2009). Like the MTL, the vmPFC has also been described as a crucial substrate of episodic memory and prospection (Bertossi, Aleo, et al., 2016; Bertossi, Tesini, et al., 2016), with some suggestion of even greater, asymmetrical impairment into future-oriented thinking relative to past or present thinking (Ciaramelli, Anelli, & Frassinetti, 2021). Indeed, patients with lesions to the vmPFC show greater short-sighted, "myopic" behaviours than healthy control participants. These patients show difficulty imagining both expected future events and atemporal, fictitious episodic events (Bertossi, Aleo, et al., 2016), and produce far fewer details and rich imagery compared to healthy controls (Bertossi, Tesini, et al., 2016).

Although both vmPFC and MTL patients express difficulties in remembering past and constructing future events, qualitative differences between the groups in generation of detail and decision-making have also emerged. A study comparing detail generation in future thinking revealed that despite both vmPFC and MTL patients showing a deficit in imagining future events, vmPFC patients generated fewer details for events relating to themselves compared to events relating to others (Verfaellie et al., 2019). These findings are consistent with the well-established role of the vmPFC in self-referential processing, especially when specifying goals or activities that are personally meaningful or that pertain to the self (D'Argembeau & Salmon, 2012; Denny et al., 2012; Stendardi et al., 2021). Separate research shows that vmPFC patients are able to describe scenes with increased vividness and detail when a specific cue is provided (Kurczek et al., 2015), suggesting that vmPFC patients can benefit from external supports that explicitly scaffold these processes despite vmPFC compromise. Thus, vmPFC patients who have impaired episodic simulation systems may benefit from cues that allow access to relevant personal information that can be used to simulate future scenarios (Benoit et al., 2014).

Recent observations in the reward discounting literature find that involving episodic cueing can provide a better understanding of this process. Numerous studies have extended the work of Peters and Büchel (2010) and Benoit et al. (2011) to test the extent in which the episodic cueing procedure modulates the reduction of delay discounting (see Rung & Madden, 2018, for a recent meta-analyses). As previously mentioned, vmPFC patients show steep delay discounting compared to controls and this may be due to difficulties initiating episodic future thinking. Alternatively, rather than exhibiting a deficit in episodic simulation, vmPFC patients may have trouble with strategic retrieval and implementation of subjective valuation, something that can be regulated with personally meaningful external cues. This hypothesis could explain why vmPFC patients who show difficulties generating details relating to themselves during tests of episodic memory and future imagining improve with more structured cueing (Kurczek et al., 2015; Verfaellie et al., 2019). This also leads to the prediction that vmPFC patients who show abnormal discounting under standard conditions should show similar benefits following the presentation of personal cues. Indeed, a recent study by Ciaramelli, De Luca, et al. (2021) found that episodic cues downregulate delay discounting equally in vmPFC patients and healthy controls. These personally meaningful external cues may help to place greater subjective value on future or uncertain rewards, even in the context of impaired spontaneous subjective valuation of rewards.

Unlike individuals with vmPFC lesions, individuals with MTL lesions do not show reduced delay discounting when engaging with personally meaningful, episodic cues (Kwan et al., 2015; Palombo et al., 2015b). Unlike vmPFC patients, the extent of the cognitive deficits observed in MTL participants is limited to impairments to their episodic memory and future thinking system. As subjective valuation for these individuals remains intact, they either

resemble controls on standard delay and probability discounting (see Kwan et al., 2012; 2013) or show greater risk-taking (as observed in Study 1). For most of these patients who have impaired episodic future thinking/extensive MTL damage, the events may be difficult to generate due to limited episodic detail and vividness (Kwan et al., 2015). For those who do show a cueing effect, their results could be better explained by circumscribed lesions that reduce, but do not eliminate episodic memory and future thinking. There may also be a greater reliance on other non-episodic abilities, such as semantic representations that are typically intact in a large number of MTL patients. For example, Palombo et al. (2016) found that providing these individuals with a semantic scaffold increased the salience of, and preference for, the future reward options. Thus, patients with MTL lesions appear to have impaired episodic thinking but not reward valuation, whereas patients with vmPFC lesions have deficits to the latter and need greater support to activate the former.

Comparatively less is known about interactions between episodic cues and probability discounting. In Study 2, we observed that episodic cues did not benefit probability discounting in either young or older adults, suggesting that the effects of these cues may be on decisions that require thinking into the future. Nevertheless, it is uncertain if the cues, in fact, interact with subjective value, as suggested by findings of benefits of the cues to delay discounting in vmPFC patients but not MTL patients. If so, then the cues should also benefit probability discounting in vmPFC patients. To this end, the present study will consider whether processing of personal events will similarly encourage optimal discounting of future and uncertain rewards. To do so, both vmPFC and MTL patients will complete a probabilistic reward tasks with and without cues similar to those used in Study 2. Again, whereas both young and older adults in the previous study showed no modulation to probabilistic discounting outcomes following event cueing,

patients with vmPFC lesions may still benefit from these cues as a form of external support, leading to more typical decision-making involving uncertainty and risks. If delay and probability discounting are atypical in patients with vmPFC lesions due to a common deficiency in activating subjective value rather than a primary episodic future thinking deficit, then vmPFC patients should see benefits to both when personally meaningful cues are used to enhance the subjective value of the rewards. This should differ from MTL patients who, based on previous findings showing a lack of modulation in delay discounting with episodic cues, should also show no benefits with probability discounting.

Methods

Participants

Focal Lesion Patients

All patients were recruited from Baycrest Health Sciences either from the patient or older adult participant databases. Patients were in the stable phase of recovery and had no additional diagnosis that would affect cognitive abilities other than those pertaining to their brain injuries.

vmPFC. Six individuals (two men; $M = 67.2$; $SD = 9.6$) with vmPFC lesions who participated in Study 1 and who were included in Ciaramelli, De Luca, et al. (2021) also participated in the current study. Five of these participants (J.W., J.A.G., M.M., M.P., and M.T.) acquired their focal brain lesions following ruptures to an anterior communicating artery (ACoA) due to an aneurysm. The remaining individual (R.L.), was identified as having a focal vmPFC lesion following an anterior cerebral artery stroke. All patients were tested between 2018 and 2021 with more than 12 months post-lesion. More information regarding their individual vmPFC lesion and neuropsychological characterization can be found in the Methods section of Study 1 and in Table 2.1.

MTL. Four individuals (all men, *M* = 57.0; *SD* = 5.8) with MTL lesions who were included in Study 1 were also tested. Of these individuals, D.A.'s lesions were the most widespread, with damage extending beyond the MTL bilaterally (though primarily right) and into ventral frontal, anterior cingulate, and occipital cortices. B. L.'s lesions to his hippocampus were bilateral and specific to the dentate gyrus and part of the CA3 subfield. Neuroimaging also revealed volume loss within the left superior parietal lobe and right precuneus. M. H. contracted herpes simplex encephalitis, which resulted in bilateral MTL atrophy and further damage to his right medial occipital and inferotemporal cortices. As mentioned in Study 1, D.G., who was one of the individuals that suffered an anoxia episode secondary to cardiac arrest, could not be scanned due to medical contraindications. MTL pathology for D.G. was inferred based on etiology and neuropsychological profile (Table 2.1).

Controls. Performance of the 36 age-matched control participants (16 men, *M* = 61.2; *SD* = 8.1) made up the older adult group in Study 2, that completed the cued probability discounting task, were compared to that of each patient group on the probability discounting task. As discussed in Study 2, the control participants were screened for variables that are typically associated with steeper than average discounting (Madden & Bickel, 2010), including smoking, significant alcohol and drug use, and gambling problems that meet diagnostic criteria in the DSM-IV-TR and DSM-5. Exclusion criteria included individuals who reported current consumption of, or engagement in, the listed substances or activities, respectively.

All participants gave informed written consent and received monetary compensation in accordance with the Human Research Ethics Committee of York University and Baycrest Health Sciences.

Probability Discounting

Task procedures in the current study are analogous to those described in Experiment 2 in Study 2 (Chapter 3). Over a series of trials, participants were presented with pairs of hypothetical monetary amounts on a computer screen and asked to make independent choices between a smaller, certain reward and a larger, probabilistic reward. Following a 30-minute delay in which the participants completed questionnaires and other cognitive tasks not included in this current study, they then completed the cued probability discounting task (see details in Study 2).

COVID-19 disruptions and virtual administration of experimental tasks

As a result of research disruptions due to COVID-19 leading to suspension of participant recruitment for in-person data collection, portions of this research study were adapted to virtual delivery. Of the six vmPFC patients, JAG and MM completed in-person testing. The remaining four vmPFC patients (JW, RL, MT, and MP), as well as MM, who was re-tested approximately one year after the first set of data were collected, were tested via virtual, remote delivery. In lieu of face-to-face, in-person testing, participation and completion of research tasks were completed via Zoom® videoconferencing software. Screen sharing and remote-control access features on Zoom® were used to facilitate synchronous interaction with participants that would mimic in-person testing. For the participants who indicated that they had less familiarity with videoconferencing technology and less overall computer literacy, the experimenter selected the response options on behalf of the participant. All other instructions for the uncued and cued probability discounting tasks were identical to the in-person experience, described in Study 2.

Results

Though previous studies have found discounting task responses to be reliable and stable across test-retest intervals for both younger and older adults (e.g., Jimura et al., 2011; Kirby,

2009), less is known about the stability of discounting tasks behaviour across repeated testing for vmPFC patients. Given our previous discussion in Chapter 2 regarding inconsistencies and irregular preference judgments for vmPFC patients *within* a task (Kurtz-David et al., 2019), this is especially relevant here as all of the vmPFC patients were retested at a later date on the standard probability discounting task and in a virtual online format. To address this, the reliability of the virtually collected data was first determined by conducting separate paired sample t-tests to compare uncued probability discounting in virtual and in-person formats for the vmPFC patients (whose data was also previously described in Study 1). As with Study 1 and 2, the degree to which participants discounted probability rewards was measured using area-under-the-curve (AuC; Myerson et al., 2001). Paired sample t-tests were conducted separately for both reward amount conditions. Given the sample size, effect sizes and the confidence intervals around those effect sizes are denoted. On average, there were no statistically significant differences between virtual and in-person tasks for either the smaller ($250) reward, $t(4) = 0.10$, $p = .93$, $d = .04$ 95% CI [-.90, 0.84] or larger ($2000) reward, $t(4) = 1.12$, $p = .33$, $d = .55$ 95% CI [-0.46, 1.41] conditions. These comparisons were further analyzed using a Bayesian approach to circumvent the limitations that classical statistical analyses may have in the case of null findings such as those described above. The Bayes factors 0.40 and 0.62, respectively, describe *anecdotal*, modest evidence supporting the null hypothesis.

With the vmPFC patient group data that was virtually collected now established as reliable, we can look at the vmPFC group alongside the age-matched subset of controls who completed the probability discounting tasks from Experiment 2 of Study 2. Figure 4.1 shows the mean subjective values of the probabilistic rewards for the uncued and cued conditions as a function of the odds against receiving those rewards for both the smaller ($250; upper panel) and

the larger ($2000; lower panel) amount conditions. From the figure, both vmPFC and controls show evidence of systematic decreases in subjective value as the odds against increased, with controls showing a steeper discounting of probabilistic rewards than the individuals in the vmPFC group in the uncued condition of the task. However, the shallowness of the discounting curve observed in the uncued condition appears to be mitigated by the presentation of event cues for the vmPFC individuals.

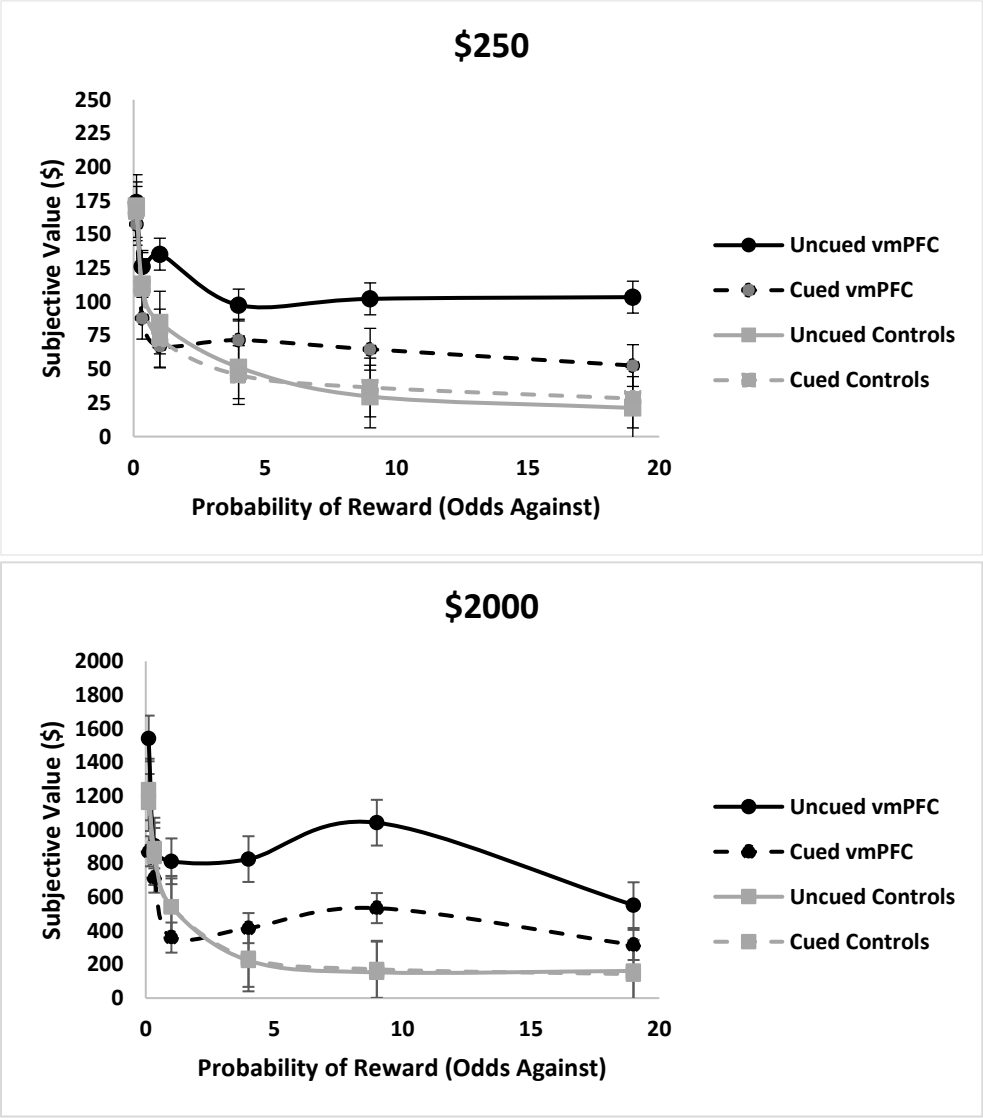

Figure 4.1. Mean subjective value as a function of the odds against receiving a probabilistic reward for vmPFC and control groups. The top and bottom panels present the data from the smaller ($250) and larger ($2000) probabilistic reward amount conditions, respectively.

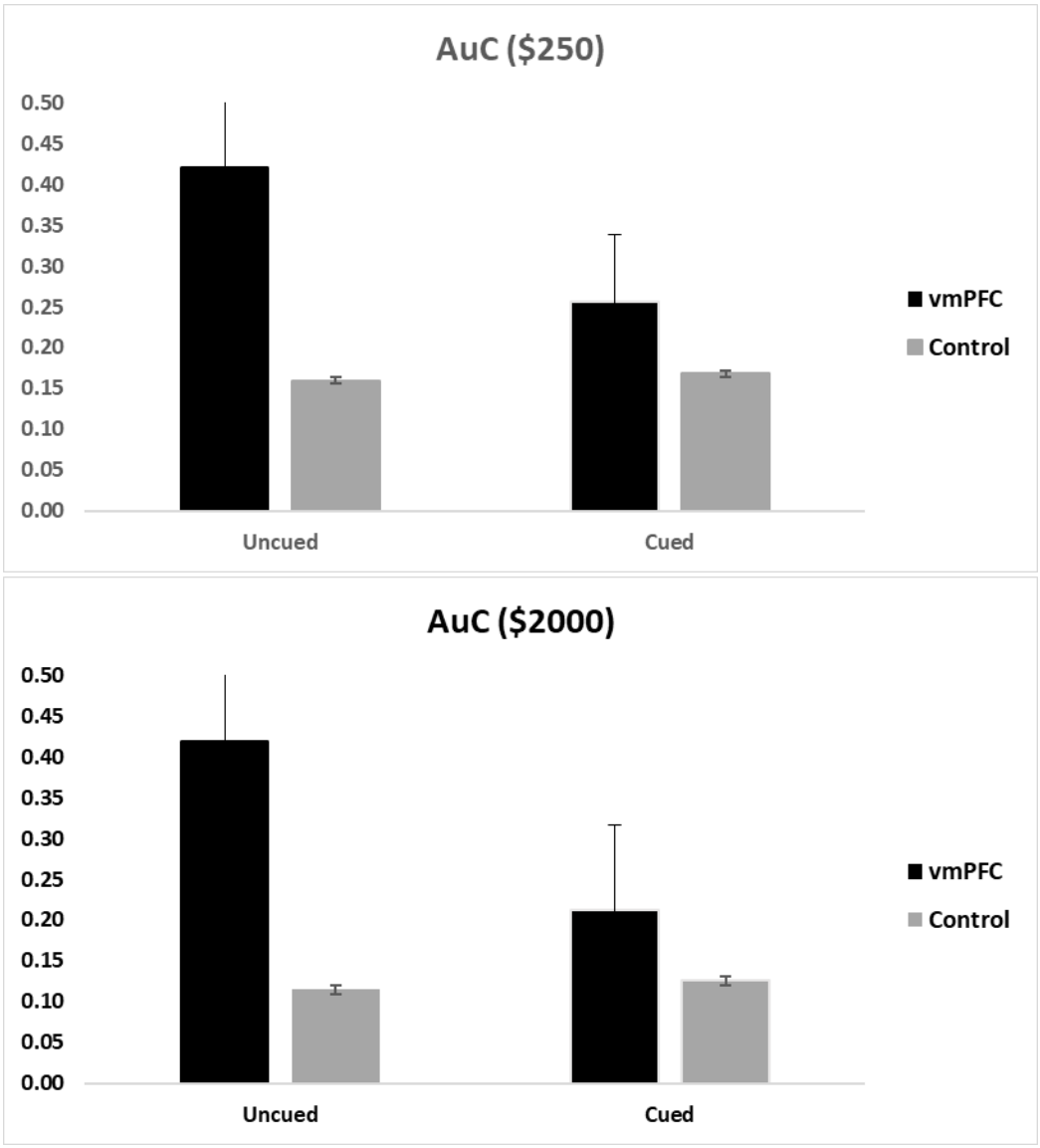

Figure 4.2. Mean AuCs for the vmPFC and Control groups. The top and bottom present the data from the smaller and larger probabilistic reward amount conditions, respectively, for both the uncued and cued conditions.

The AuCs were included in a 2 (Group: vmPFC vs. Control) x 2 (Condition: Uncued vs. Cued) x 2 (Reward Amount: Small vs. Large) mixed factorial design analysis of variance (ANOVA). Significant effects for Condition and Group conditions were observed, $F(1,40) = 10.11$, $p = .003$, $\eta_p^2 = .20$, and $F(1,40) = 12.14$, $p = .001$, $\eta_p^2 = .23$, respectively. This was qualified by a significant Condition x Group interaction, likely reflecting the steeper discounting of the probabilistic reward choices in the cued condition compared to the uncued condition for the vmPFC group but not the Control group, for both reward amounts, $F(1,40) = 12.38$, $p = .001$, $\eta_p^2 = .24$ (Figure 4.2). A measure of the cueing effect (described as the mean difference score between cued and uncued AuCs across the two reward amounts; see Kwan et al., 2015) revealed a statistically significant difference in scores between the vmPFC ($M = -0.19$, $SD = 0.21$) and Control groups ($M = 0.009$, $SD = 0.11$), $t(40) = 3.52$, $p = .001$, $d = 1.55$. No statistically significant effects of Amount ($p = .12$) or Amount x Group interaction were observed ($p = .60$). Although, as expected, in the uncued condition, the vmPFC group discounted less steeply than controls in both the small ($t(40) = -4.14$, $p < .001$, $d = -1.83$) and large reward conditions, $t(40) = -4.75$, $p < .001$, $d = -2.09$. Notably, this pattern was not observed in the cued condition for either the small ($p = .22$) or large ($p = .20$) reward conditions.

To determine whether the event cues prompted more "optimal" or normalized discounting behaviours for the vmPFC patients, planned independent samples *t*-tests were conducted to compare the AuCs of the vmPFC group for the cued condition with the AuCs of the Control group for the uncued, baseline condition. As expected, no differences were observed at the small $t(40) = -1.61$, $p = .12d = .71$, or large conditions, $t(40) = -2.00$, $p = .053$, $d = .88$. For verification, Bayesian independent samples *t*-tests were also conducted on the comparisons between the cued AuC scores for vmPFC and the uncued AuC scores for the Control group. The

Bayes factors were 0.97 and 1.57, for comparisons among the small and large amounts, respectively. These values describe *anecdotal*, modest evidence supporting the null hypothesis. Contrast these results with the Bayes factors reported for the direct comparisons between the vmPFC and Control groups for the uncued small (BF = 113.85) and large reward (BF = 555.72) conditions. These results describe extreme evidence for the alternative hypothesis and affirm that there are significant comparative differences between the discounting of probabilistic rewards across the two groups for both reward amounts (Lee & Wagenmakers, 2013).

Table 4.1. Cueing Effect Comparison for Probability Discounting Task for vmPFC and MTL participants compared to Controls

Participant	*M*	*t*	*p*	z_{cc}
vmPFC				
JAG	-0.03	-0.34	.73	-0.35
JW	-0.19	-1.84	.07	-1.87
RL	-0.49	-4.56	< .0001	-4.62
MM	0.08	0.68	.50	0.69
MT	-0.12	-1.21	.24	-1.22
MP	-0.37	-3.45	< .001	-3.50
MTL				
MH	-0.04	-0.47	.64	-0.48
DA	-0.06	-0.64	.53	-0.65
DG	0.07	0.53	.60	0.54
BL	0.04	0.29	.77	0.29
Controls (n = 36)	-0.009 (0.108)			

Note: Value in parentheses is standard deviation for Control group; z_{cc} = effect size for the difference between case and controls (Crawford et al., 2010). Bonferroni corrected significance level of .008 was calculated for vmPFC patients; significance level of .01 was calculated for MTL patients.

Three of the six vmPFC patients in the current study (M.M., R.L., and M.P.) have damage that extend to the lateral prefrontal cortex (dlPFC), which has previously been implicated in the magnitude effect (Ballard et al., 2018). To assess the veracity of the current findings, a single case-study approach was employed to compare the cueing effect for individual patients relative to the performance of the control group. Table 4.1 shows the results of the modified independent samples *t*-tests that were conducted for each of the patients with a point estimate indicating the difference between the patient and the mean control score (Crawford et al., 2010). Two of the three individuals with extended dlPFC lesions, R.L. and M.P., had significant differences in cueing effects compared to the Control participants (both *p*s < .001); this significant difference was retained even after a Bonferroni-adjustment ($\alpha = .008$). M.M., the other participant with dlPFC damage, showed a positive cueing effect, such that event cue presentation increased subjective risk-taking ($p = .50$). No other statistically significant differences were observed between the remaining vmPFC individuals and controls (all other *p*s > .07).

M.M.'s cueing effect was in a positive direction, which suggests an increased preference in the larger, albeit riskier reward options when cued with personally meaningful events. This runs counter to the other vmPFC patients who all showed a dampening of their discounting curves following the presentation of event cues. As M.M. was tested both virtually and in-person, it remained to be seen whether his performance was also consistent across multiple testing sessions and under different formats. Direct comparison of M.M.'s cueing effect for both his earlier in-person testing and virtual testing results was performed using a modified Crawford's t-test to compares two single case results (Crawford et al., 2010). This modified t-test compares two cases to determine whether the difference between cases is an observation from

the distribution of pairs of differences in the control sample. Results revealed no significant difference between his previous and more recent performances, $t(35) = 1.06$, $p = .30$.

Figure 4.3 compares the mean subjective values of the probabilistic rewards for the uncued and cued conditions as a function of the odds against receiving those rewards for the MTL and Control groups. From the figure, the MTL group, similar to the controls, show evidence of systematic decreases in subjective value as the odds against increased, with the MTL group showing shallower uncued and cued discounting curves for the smaller reward amount conditions compared to controls. For the larger reward condition, the MTL uncued discounting curves appear steeper in comparison to the cued discounting curve and for both curves for the Control group.

As with the vmPFC comparison, the AuCs were included in a 2 (Group: MTL vs. Control) x 2 (Condition: Uncued vs. Cued) x 2 (Reward Amount: Small vs. Large) mixed factorial ANOVA (see Figure 4.4). Significant effect of Amount was observed, $F(1,38) = 9.97$, $p = .003$, $\eta_p^2 = .21$, which may reflect the expected magnitude effect (shallowing discounting of smaller probabilistic rewards compared to larger rewards) observed across both groups. When collapsing over the levels of the Group and Cueing condition, post hoc comparisons of the reward amounts revealed a statistically significant mean difference between the small and large conditions even after Bonferroni-adjustment, $t(38) = 3.16$, $p = .003$, $d = .50$. No other interactions or effects were statistically significant.

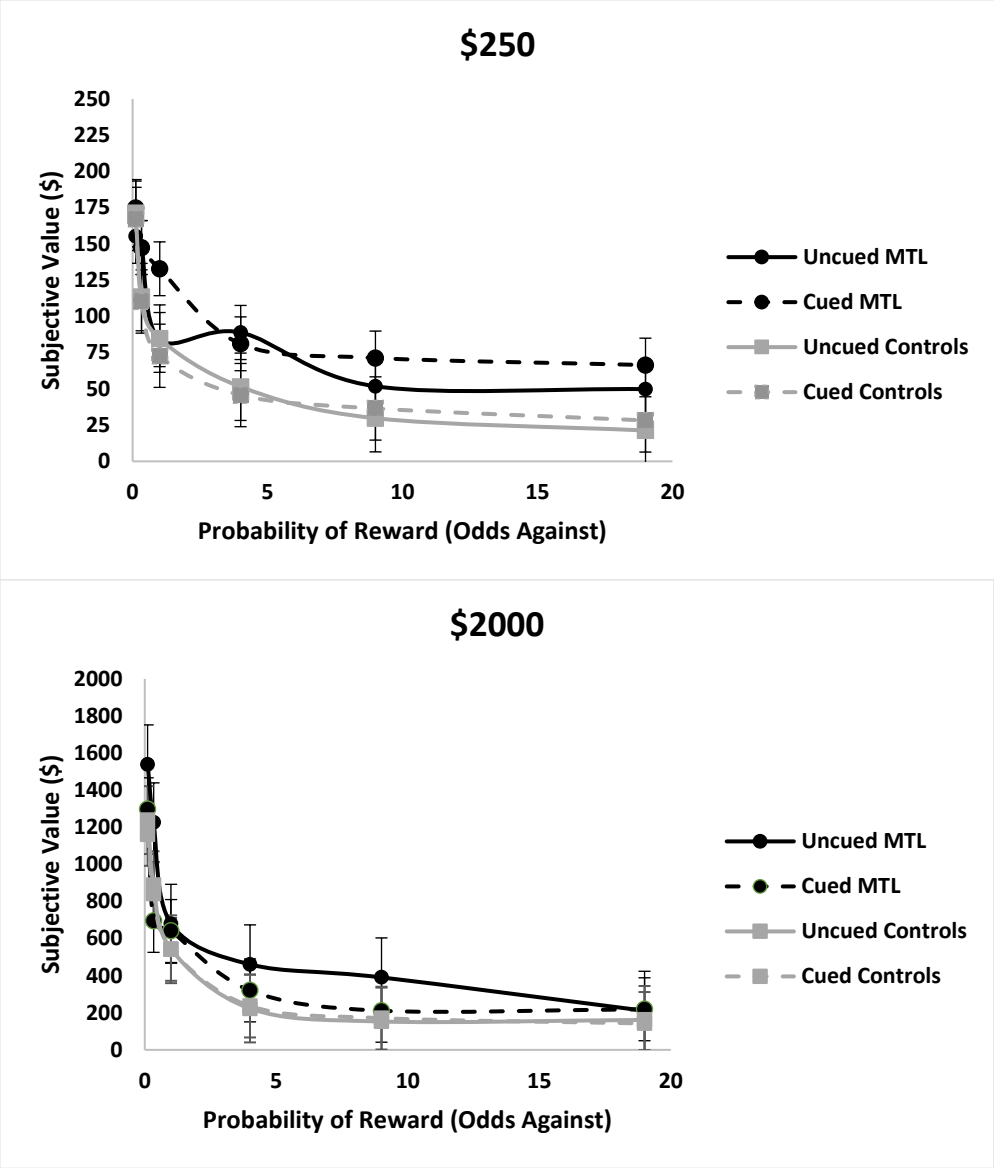

Figure 4.3. Mean subjective value as a function of the odds against receiving a probabilistic reward for MTL and control groups. The top and bottom panels present the data from the smaller ($250) and larger ($2000) probabilistic reward amount conditions, respectively.

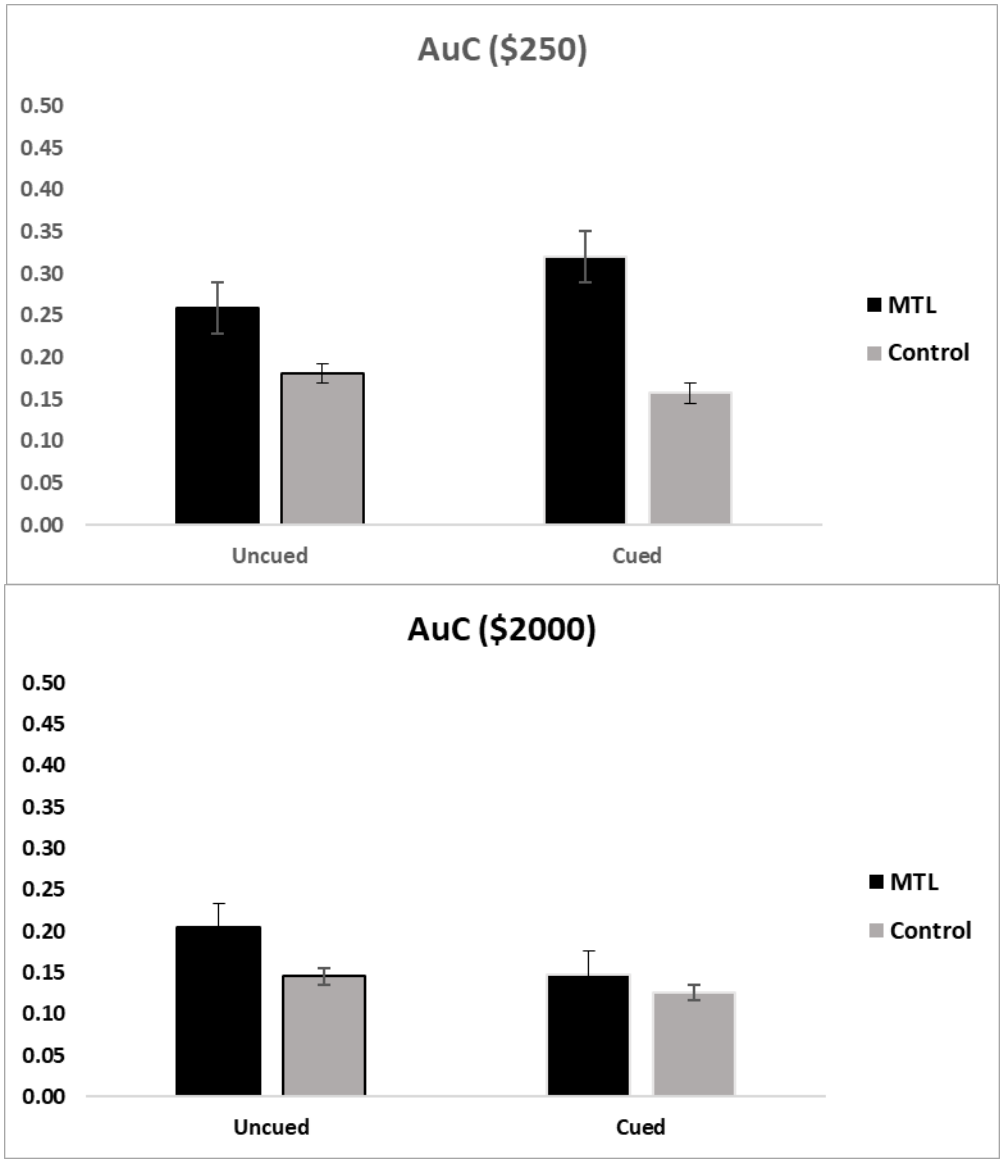

Figure 4.4. Mean AuCs for the MTL and Control groups. The top and bottom present the data from the smaller and larger probabilistic reward amount conditions, respectively, for both the uncued and cued conditions.

Following the analyses conducted for the vmPFC group, individual discounting performance was also assessed using modified independent samples *t*-test to compare single case studies with controls (Crawford et al., 2010). No statistically significant differences in cueing

effect were observed between each of the four MTL participants and their control counterparts (all *p*s > .53; see Table 4.1).

Discussion

In this study, we further examined the possibility of a shared process for delay and probability discounting by returning to the patient-lesion approach. We separately compared the performance of vmPFC-lesioned individuals and of MTL-lesioned individuals to that of neurotypical age-matched control participants on a probability discounting task, with and without the presentation of personally meaningful event cues. By doing so, we aimed to determine whether probability discounting, which also involves subjective valuation of rewards, would be scaffolded by external cues to simulate future episodes in patients with lesions to brain regions that are implicated in reward valuation and episodic simulation. Visual inspection of the discounting curves for the vmPFC patients revealed a magnitude effect that is in line with the discounting literature, where smaller reward amounts were discounted to a lesser degree than larger, less certain reward amounts. Findings in the vmPFC-lesioned participants in the current study also reproduced previous results that highlight a general tendency for shallower discounting of probabilistic rewards compared to controls, speaking to the reliability of the findings. Important to the purpose of the current study, a cueing effect was observed in the vmPFC-lesioned group, with steeper discounting following the presentation of the event cues. In contrast, the other patient group with MTL lesions did not show any significant effects of cueing on their choice of probabilistic rewards. Notably, however, these MTL participants did show the same response pattern as the vmPFC-lesioned group with respect to shallower discounting of the smaller rewards relative to the larger reward.

This study extends the findings of Studies 1 and 2 by demonstrating differences in performance for delay and probability discounting in focal lesion patients. The first study in this dissertation showed a dissociation between delay and probability discounting in vmPFC patients, providing additional evidence that these two kinds of discounting involve separate theoretical processes. The opposite weighting of immediate and probable rewards for the vmPFC patients, but not for the MTL patients or matched controls, prompted the additional question of whether we could expect a similar role for the vmPFC in probability discounting as it does for delay discounting in assigning subjective value to a reward. The pattern of performance observed in vmPFC patients, but not in MTL patients or controls, suggests that deficits in reward-based decision-making following vmPFC damage do not simply reflect a concurrent deficit in future-oriented thinking. If so, we would have expected the MTL patients to show similar modulatory benefits from episodic cues in probability discounting in the current study, and in delay discounting in previous studies (Kwan et al., 2015; Palombo et al., 2015b). That we did not find modulation of discounting with personal cues in MTL patients here or in previous studies suggests that impaired episodic future thinking is unlikely to be the root cause of the vmPFC patients' atypical discounting, although enhancing it can aid discounting.

Past studies support a relationship between risk-taking and future-oriented thinking, with impaired performance possibly due to a subjective overemphasis on the present that leads to a failure to consider future consequences of immediate choices (Thorstad & Wolff, 2018; see Kooj et al., 2018). The vmPFC, along with the MTL, may serve such a role in a network of brain regions that are involved in episodic content retrieval and processing. Yet, some of these studies suggest that the vmPFC may not only support mental time travel and might also contribute to other relevant representations and processes (Hiser & Koenigs, 2018; McCormick et al., 2018).

The vmPFC, specifically, has been largely implicated in goal-directed behaviours (Bartra et al., 2013; Clithero & Rangel, 2014). Activity in this region increases when explicitly imagining rewards and comparing values between different outcomes (Bray et al., 2010; Hare et al., 2014). Due to its role in reward valuation and risk-taking sensitivity (Blankenstein et al., 2017; Engelmann & Tamir, 2009; Seaman et al., 2018), it is theorized that the vmPFC serves as the mediator for a domain-general subjective valuation system. Thus, one possibility is that vmPFC patients perform poorly on tests of intertemporal choice because they have difficulty assigning reward value to decisions. Furthermore, if this deficit is temporally agnostic, vmPFC patients should also perform poorly on tests of probabilistic discounting. Indeed, this was observed in vmPFC lesion patients for delay discounting tasks (i.e., steeper discounting rates; Peters & D'Esposito, 2016; Sellitto et al., 2010; but see Fellows & Farah, 2005) and when assayed alongside probability discounting paradigms (shallower discounting rates; Peters & D'Esposito, 2020; but see Pujara et al., 2015). These patterns were observed in Study 1 and in this current study for our vmPFC patients.

To test the possibility that impaired performance on both discounting tests is due to impaired subjective valuation, the current study presented personal event cues to the focal lesion patients during the discounting tasks. The cues may enhance future thinking by making the reward more personally meaningful and, thus, increasing their subjective value. In healthy individuals, episodic future thinking encourages the consideration of future payoffs, leading to the reduction of delay discounting (Boyer, 2008; Peters & Büchel, 2010). Again, MTL patients, who have impaired future imagining, show comparable discounting behaviours during and probability discounting (Kwan et al., 2012; 2013) but show no evidence of additional modulatory benefits from episodic cueing (Kwan et al., 2015; Palombo et al., 2015b). Since episodic future

thinking is also compromised following vmPFC lesions, one might expect similar patterns of results in MTL and vmPFC patients. Damage to the vmPFC does not strictly impair the recollection of detail, however, and may instead impair the integration of past episodic details into imagined future events (Benoit et al., 2014; Lin et al., 2015). Based on this, there is likely to be differences in the effects of personal event cues on decision-making between the patient groups. Indeed, Ciaramelli, De Luca et al. (2021) recently showed that vmPFC patients do benefit from cueing and that the event cues lead to more optimal decision choices in reward discounting.

Additional, possibly related, reasons why personal cues lead to more optimal choices on the probability discounting task in the vmPFC patients are that they help guide interpretation of ambiguous stimuli and integrate novel experiences in the context of existing schemas. The vmPFC, is believed to activate schemas that are necessary for achieving one's goals (D'Argembeau & Mathy, 2011; Ghosh et al., 2014; Irish & Piguet, 2013). With respect to episodic simulation, vmPFC damage may lead to a deficit in the retrieval of schema-related information and, thus, loss of temporal, causal, evaluative, and social information that situates a personal event (Ciaramelli et al., 2019; Lieberman et al., 2019). Schemas are knowledge structures used to interpret changes in ongoing experiences to determine appropriate actions for ambiguous stimuli and events, which, in turn, are integrated into existing schemas (Hebscher & Gilboa, 2016). The vmPFC has been linked to schema instantiation and representation, and damage may lead to deficient schema reinstatement (Ghosh et al., 2014; Hebscher & Gilboa, 2016). It is possible that patients with vmPFC damage perform atypically on tests of delay and probability discounting due to this deficiency in schema re-instantiation. The current study suggests that personal cues provide a scaffold to externally activate a relevant self-schema in

vmPFC patients, leading to more optimal reward valuation. That these cues work with decision-making even when the decision is probabilistic and not just future-oriented favours this interpretation. These findings also provide further evidence that delay and probability discounting both rely on the vmPFC in similar ways despite their theoretical differences.

Importantly, we also investigated the extent to which the cueing effect drove optimal decision-making in our vmPFC group. At both the group and individual level, the response behaviours for the vmPFC participants were more in line with the baseline probabilistic choices made by the controls. Exceptions to these results were observed in two of the three vmPFC patients whose neurological profile show that their lesions extend to the dlPFC, an area of the brain that has been implicated in reward magnitude. That these two individuals still produced a cueing effect that was in the expected direction (i.e., steeper probability discounting following event cues) provides further support for the schema framework. The third individual (M.M.) who also had lesions to the dlPFC, did not show a significant cueing effect, and his discounting was numerically in the opposite direction to that of the other vmPFC participants (i.e., shallower probabilistic discounting following event cue presentation). Although these results are unexpected, they may reflect his severe anterograde amnesia as well as elevated impulsiveness relative to other patients. Indeed, at the end of the testing session, when prompted to describe any strategies that he employed, M.M. self-reported that he was more inclined to choose the random (probable) reward over the more guaranteed reward. His preferences were not mediated by event cues. In fact, he stated that he was too focused on the task, and he would regularly forget the cue that was presented despite having the cue presented to him throughout the selection procedure. Repeated testing sessions with M.M. provided similar, irregular preference for riskier rewards following the presentation of personal event cues. Indeed, on the Barratt Impulsiveness Scale

(BIS-11), which is a 30-item self-report instrument used to assess impulsivity, M.M. scored 74, which is above the threshold of 72 typically used to rate someone as being highly impulsive (Stanford et al., 2009). All other vmPFC patients scored below this threshold, suggesting that M.M. may have at least responded in a manner that was indicative of a more impulsive response style.

Finally, we must also consider the lack of observable cueing effect, in either direction, for the MTL patient group. Comparatively less is known regarding the effects that damage to the MTL has on schema-related processes (Irish & van Kesteren, 2018; but see Kan et al., 2009). An important question is how hippocampal damage affects schema-related encoding and retrieval of information, and, by proxy, its contribution to decision-making processes. The hippocampus is involved in the construction of vivid and detail-rich experiences and may engage with the vmPFC during both retrieval and simulation of episodic experiences (memory or future-oriented thought) to conjure and provide elaboration of these mental events (Barry et al., 2019; D'argembeau, 2020; McCormick et al., 2018, 2020). Perhaps this may explain why MTL patients show comparable performances to control participants in both delay and probability discounting but have not previously shown an effect of episodic cueing (Kwan et al., 2015; Palombo et al., 2015b) in delay discounting nor any modulatory effects in probability discounting as described in this current study. For vmPFC patients, who have deficits to both reward valuation and future thinking, personally meaningful cues may circumvent schematic instantiation problems by tapping into their intact MTLs and creating a representative schema that allows for optimal decision-making. Delay discounting has been well established in the literature to be amenable to episodic future thinking and related cueing. Probability discounting, which may be less sensitive to the episodic simulation process, as we observed in Study 2, may

still be modulated when a certain threshold of reward valuation impairment has been met, as is the case for the vmPFC patients across both delayed and risky reward choices. On the other hand, MTL patients' basic deficits are in the assembly of episodically simulated events rather than in valuation per se and may, therefore, not show benefits for any forms of episodic cueing during decision-making because of their inability to sufficiently conjure personally meaningful events to aid in making more optimal selections.

Conclusion

This study provides evidence in support of a shared neurocognitive process that helps modulate the subjective reward valuation of delay and probability discounting that may rely on the multifaceted contributions of an intact vmPFC in reward valuation, episodic future thinking, and schema representation. In vmPFC patients, but not their MTL counterparts, we see the benefits that subject-specific cues may have on supporting situationally relevant schemas that reduce atypical decision-making. Future studies are needed to specify the degree to which a schema is actively generated, such as by having participants narrate their constructed experiences in detail to define and capture individual schemas during the decision-making process more reliably (see D'Argembeau & Mathy, 2011; Kurczek et al., 2015). For now, the current findings provide support for the idea that the vmPFC contributes a self schema to reliably valuate rewards for optimal decision-making.

CHAPTER 5

General Discussion

Across three studies, I examined the neurocognitive basis of delay and probability discounting using patient-lesion and cognitive aging approaches. My dissertation focused on two important issues at the intersection of decision neuroscience and memory research. The first issue, one that has intrigued decision-making researchers, is whether delay and probability discounting share a common process. While these tasks resemble each other mathematically and may even share a common language of impulsiveness to describe both effects, previous investigations exploring the relationship between delay and probability discounting have been inconsistent. One way of clarifying the possible relationship between these two types of discounting is to examine the neural mechanisms that help give rise to delayed and risky reward choices. This question involves the second area of interest within my dissertation, which is to explore whether select regions of the brain, when compromised, show a bias towards impaired or atypical discounting. More specifically, my dissertation considered the contributions of the vmPFC and the MTL to decision-making. The vmPFC, which is involved in both reward valuation and episodic simulation, is of particular interest given that both of these neurocognitive processes can contribute to reward discounting. The following section describe the results from the three studies.

Summary of Findings

This dissertation reports three studies that attempt to clarify if distinct brain regions contribute in a similar way to reward discounting and whether these contributions are similarly modulated by episodic imagining. In my first study, I used a patient-lesion approach to shed light on the possible relationship between delay and probability discounting at a neural level by

examining individual and group differences between delay and probability discounting in patients with vmPFC lesions, MTL lesions, and matched controls. Overall, I found that MTL-lesioned individuals discounted delayed rewards at normal rates but discounted probabilistic rewards more shallowly than controls. vmPFC-lesioned individuals also discounted probabilistic rewards more shallowly than controls, but unlike MTL patients, discounted delayed rewards more steeply than controls. These results suggest that vmPFC lesions affect the weighting of reward amount relative to delay and certainty in opposite ways. Moreover, whereas MTL-lesioned individuals and controls showed typical, nonsignificant correlations between the discounting of delayed and probabilistic rewards, vmPFC-lesioned individuals showed a significant negative correlation. The results of Study 1 appear to challenge the previously held belief that a single mechanism governs valuation of both delayed and probabilistic rewards.

In Study 2, I turned to investigate the adaptive value of episodic imagining on reward discounting in a healthy aging population. Older adults typically experience age-related structural and functional changes to the MTL, resulting in a gradual decline in simulating vivid future experiences. How this compares to younger adults in reward discounting is of particular interest since we can determine whether conditions that affect episodic memory and future imagining (e.g., healthy aging), can be supported by externally generated event cues to increase the subjective value of future and risky rewards. In Study 2, I found that cued episodic imagining decreased the discounting of delayed rewards in both young and older adults. This effect was significantly less pronounced in older adults, however, matching the expected age-related decline that is typically observed in episodic imagining. Moreover, in contrast to the effects of cueing on delay discounting, personally relevant event cues had little or no effect on the discounting of probabilistic rewards in either young or older adults.

Findings that the vmPFC may be involved in both delay and probability discounting, albeit in different (possibly opposite) ways (Study 1), and findings that imagining personal episodic cues differentially affects delayed and risky rewards (Study 2), laid the groundwork for Study 3. In Study 3, I returned to the patient-lesion approach to gain further insight into the contributions of the vmPFC to reward discounting. Findings that externally generated episodic event cues can benefit neurotypical older adults in delay discounting, even when this effect is not observed in MTL patients (see Kwan et al., 2015), points to other neurocognitive processes that are called on to discount rewards. The vmPFC has been identified as a brain region that is critical to subjective valuation of rewards, possibly through the organization of information and multiple reward attributes (e.g., immediacy, likelihood) that are integrated into an optimal decision (Blankenstein et al., 2017; Vaidya et al., 2018). Furthermore, the vmPFC also plays a prominent role in episodic memory and future thinking, working in conjunction with the MTL/hippocampus to retrieve and organize episodic details during the simulation of episodic events (Bertossi, Tesini et al., 2016; Campbell et al., 2017). Given the findings of Study 1 on the pattern of delay and probability discounting observed in this patient group (i.e., steep discounting of delayed rewards and shallow discounting of risky choices), it remained to be seen whether personal episodic cues would similarly lead to more optimal discounting of probabilistic rewards. To that end, I investigated the effects of episodic cueing on probability discounting in both vmPFC and MTL patients using the same cued probability discounting task from Study 2. Similar to previous findings with delay discounting, I did not find evidence that episodic cues modulate discounting of probabilistic rewards in MTL patients. Of the six vmPFC patients recruited for my third study, five demonstrated a cueing effect that reflected a greater tendency to choose the less risky, smaller reward choices compared to the baseline condition when no cues were given.

Importantly, subsequent analyses showed that the episodic cues had *normalized* the responses of the vmPFC patient group such that their discounting was comparable to that of the controls in the baseline condition. These findings suggest that there are considerable differences in the effects of personal episodic cues on decision-making between MTL and vmPFC patients and, within the latter group, effects of cues on both delay and probability discounting, which had not previously been found in young adults or older adults or in the MTL patients who were tested here.

The findings across all three studies show that the vmPFC plays a critical role in reward valuation, which is required for discounting of both farsighted and risky rewards (Studies 1 and 3), whereas the MTL plays a role that may be limited to probability discounting (Study 3). Moreover, cues to imagine specific episodes coinciding with receipt of rewards may work to enhance subjective value of rewards via activation of a personal event or schema (Studies 2 and 3).

Instantiation of a self-schema to enhance subjective valuation of rewards

The present set of studies support findings of earlier research that argue for different mechanisms that underlie discounting of delayed and risky rewards. Central to this investigation was the contributions of the vmPFC, an area of the brain that has been ascribed a wide array of higher-order functions (e.g., Kable et al., 2020; Stuss & Levine, 2002). Two purported functions of the vmPFC – reward valuation and episodic future thinking – might help us better understand different forms of discounting and whether there is, indeed, a common process that unifies them. First, findings from Study 1 support the primary contribution of the vmPFC in reward valuation. Although the tendency to devalue rewards that are found in the distant future is ubiquitous to intertemporal choice, vmPFC patients showed a pattern of responding to delayed rewards that was atypical, in line with previous studies showing increased vmPFC sensitivity to increasing

immediate choices and to changes in reward valuation during situations of increased impulsivity (Manuel et al., 2019; Jimura et al., 2013). Likewise, vmPFC participants also showed atypical responding during probability discounting, suggesting that a common "neural currency" of reward valuation may be impaired across both delayed and risky rewards in vmPFC patients. In comparison, reward valuation appears to be intact in MTL patients, who were found to be more similar to controls in their discounting. Episodic future thinking, another cognitive process that is believed to rely on the MTL and to involve vmPFC, is thought to reduce delay discounting in neurotypical adults by promoting vivid representations of the self to enhance the value of future payoffs (Benoit et al., 2018; Boyer, 2008; Bulley & Schacter, 2020). Findings from Study 2 appear to support this explanation, as healthy adult participants show reduced delay discounting following the presentation of personally relevant event cues, with older adults showing a dampened effect, possibly due to age-related decline in MTL integrity and reduced episodic imagining capacity. This explanation is further supported by early findings that the modulatory role of episodic simulation on delay discounting is largely abolished following MTL lesions (Kwan et al., 2015; Palombo et al., 2015b; see also Kaplan et al. 2016).

Unlike individuals with MTL lesions, individuals with vmPFC lesions do benefit from personal cues, and not only in reducing delay discounting, as had been demonstrated by Ciaramelli, De Luca, et al. (2021), but also in probability discounting, as demonstrated in Study 3. No other participant group tested in the current dissertation showed benefits of personal cues on the probability discounting task (Studies 2 and 3), and thus far, personal event cues have only been shown to optimize risky decisions when they are made in the context of future outcomes (see Kaplan et al., 2016). This dissociation in the effects of episodic simulation between vmPFC and MTL patients suggests that the personal cues had an effect on subjective valuation of

rewards, which is impaired in the vmPFC patients. Episodic future thinking alone may not be necessary for typical discounting, especially in circumstances where subjective valuation is likely intact (e.g., MTL patients). However, episodic future thinking may still be relied upon to help with atypical discounting. One possibility is that that these episodic cues activate event schemas to contextualize the rewards or make them more concrete. Crucially, the vmPFC is involved in this process, as its connectivity to different sensory modalities enables it to facilitate the instantiation of schematic representation when we encounter novel or unique information. The vmPFC serves as a "gatekeeper" for incoming information so that these new information and experiences could be matched to existing schemas and associated with valence and value (D'Argembeau et al., 2012; Hebscher & Gilboa, 2016; Lieberman et al., 2019).

As we discussed in Studies 1 and 3, the opposite weighing of delay and probability rewards for vmPFC patients argues against a common process underlying these two forms of discounting. Nevertheless, the modulatory effects following presentation of event cues are apparent with vmPFC patients, indicating that both tasks rely on the vmPFC in some shared capacity to evaluate choice options. Damage to the vmPFC may lead to a failure to instantiate personal event schemas. However, once activated, the schemas successfully interact with rewards to enhance their value. Consistent with this idea, synchronous and bidirectional engagement of the vmPFC and MTL have been observed during retrieval of autobiographical memory and scene construction, with the vmPFC primarily driving the activity observed in the hippocampus during both initiation and elaboration of mental events (Barry et al., 2019; McCormick et al., 2020). Whereas the MTL is primarily involved in retrieval of episodic details during episodic future thinking, it has been proposed that the vmPFC is involved in both the activation of relevant schematic knowledge that drives the retrieval and integration of these

details to foster the construction of specific future episodes (Campbell et al., 2017; McCormick et al., 2018).

The organization of self-schemas (D'Argembeau & Mathy, 2011), which involve the integration of surrounding environmental cues, activities, objects, and social elements to help generate the cognitive heuristics needed to support everyday experiences, is likely to drive the elements that help us to make optimal choices (Hebscher & Gilboa, 2016; Wang et al., 2020). Thus, it may be that these episodic cues help increase reward value of either future or less risky reward choices (Lin et al., 2015). As we saw in Study 1, vmPFC patients are unable to make both temporally contiguous and risk-aversive decisions, each of which require weighing of two reward values. We have seen that vmPFC patients are not impaired in constructing future events or scenes in laboratory tasks that are scaffolded and requires less self-initiation (Kurczek et al., 2015; McCormick et al., 2017; Verfaellie et al., 2019). vmPFC patients who appear to be unable to imagine vivid details of future events become less impaired in constructing detailed episodes regarding their personal future once they are given more self- and situationally relevant schemas to organize their thoughts (e.g., imagining autobiographical event narratives or being provided with self-relevant cued words; Kurczek et al., 2015; Verfaellie et al., 2019). In the current studies involving episodic cues, personal event cues likely act as external supports to initiate optimal decision-making. It is possible that episodic cues might be more sensitive to delay discounting. However, if probability discounting is below a certain threshold, as is the case in vmPFC patients, then episodic cues will be effective in leading to more optimal decisions. This interpretation explains why MTL patients do not benefit from laboratory tasks that support self-instantiation in the same way that vmPFC patients do (Kurczek et al., 2015). It would also explain why we do not observe systematic differences between MTL patients and controls in

both uncued and cued reward discounting, whether delayed or probabilistic. MTL-lesioned individuals who have impaired episodic future thinking are unable to generate the episodic content needed to benefit from the cues in the same way as the vmPFC patients (Kwan et al., 2015; Palombo et al., 2015b). Rather, they require cues that interact with preserved areas of function, such as those that would allow them to access preserved semantic representations of future rewards (e.g., the actual item that would be purchased at the time of the delayed reward; Palombo et al., 2016).

Although the suggestion that the vmPFC serves a role in activating self-schemas is not new, findings from my dissertation shows that there is a novel way to approach this well-documented function. Self-schema instantiation reconciles why separate theoretical processes underlie delay and probability discounting by showing that the vmPFC maintains a central role in both. Hiser and Koenigs (2018) described the vmPFC as an area containing functionally specialized subregions, with each subregion characterized by a pattern of connections with cortical and subcortical structures appropriate to the subregion's function. This could account for the apparent paradox of differential weighting of rewards and modulatory direction following episodic cueing, as self-schemas serve as a strategic process to signal the expected value of personally meaningful events, which can then be used to mediate more farsighted and risk-aversive decisions. Yu et al. (2019) advanced such a framework, proposing that schema instantiation may connect future imagining, episodic memory, decision-making, valuation of rewards, and other higher-order cognitive processes into a single domain that is chaired by the vmPFC. Impaired self-schemas would produce the cognitive deficits typically seen in humans following lesions to the vmPFC (see Kan et al., 2020 for a discussion). This integrative framework could mean that personally meaningful event cues serve as a scaffold that produces

more coherent decision-making, thus reducing delay discounting and, quite possibly, supporting other forms of decision-making (e.g., decisions such as those in the present study that involve risky or probabilistic outcomes). This framework contributes to the multifaceted role of the vmPFC and appears to support the findings that both delay discounting (Ciaramelli, De Luca, et al., 2021) and probability discounting (Study 3 of the current dissertation) are modulated by personal event cues in vmPFC patients. Self-relevant cues help to circumvent vmPFC patients' schema initiation problem. Once a schema is externally activated, the patients' intact MTLs allow them to construct personal event details that can be integrated into both delay and probabilistic decision-making.

vmPFC as a mediator of neural networks involved in reward discounting and adaptive decision-making

In light of the findings across the three studies, reward discounting of delayed and risky rewards appears to converge prominently on the vmPFC as it serves as a common neural substrate of reward valuation. While this is a plausible basis, some considerations can be made that this may not necessarily be the prerequisite for adaptive decision-making. Instead, the delineation of delay and probability discounting that we observed across the three studies not only suggest that these two types of reward discounting can be viewed as separable traits, but that they also should have distinct or adjacent neural circuitry to go along with each. Having separate neural networks for delay and probability discounting also suggests that there are domain-specific neurocognitive processes that may be relied upon for one type of discounting choice over the other. Most notably, Peters and Büchel (2009) found that activation of the frontal pole regions were correlated more closely with delay discounting, suggesting that decisions involving delayed rewards is likely mediated by the elaboration of future scenarios more so than risky rewards. This affirms what we have observed with episodic cues during intertemporal

choice and helps to explain the possible threshold required for episodic cues to benefit reward discounting across domains. In a similar fashion, their study showed that clusters of brain regions (i.e., superior parietal and middle occipital regions) that are typically involved with magnitude valuation and numerosity, could be recruited selectively for the valuation of probabilistic and risky reward choices (Lasne et al., 2019; Piazza et al., 2007).

If delay and probability discounting are indeed distinct from each other, what further purpose does the reward valuation system and, consequently, the vmPFC hold in reward discounting? As we have postulated, schema instantiation involving a series of cognitive processes that relies on or involves the vmPFC may help to modulate reward discounting. Thus, the vmPFC may be described as a mediator for the intersection of cognitive functions used to enact goal-directed behaviour. Hiser and Koenigs (2017) suggested that at least three specialized domains of cognitive and psychological functioning may exist for the vmPFC: social (re)cognition, generation and regulation of negatively-valenced emotions, and the representation of reward- and value-based decision making. My dissertation highlights the contributions of the vmPFC on the latter of these processes, but other areas of the brain, those that form neural networks or connections with the vmPFC, are also prominently involved in the other two processes, as well as adaptive decision-making and in reward discounting. An important area is the ventral striatum, which is functionally related to the vmPFC and together forms a core network involved in processing magnitudes and predictors of rewards (Diekhof et al., 2012), as well as the short-term, neural processing of predicted reward values during delay discounting tasks (Gregorios-Pippas et al., 2009). The role of the vmPFC as a mediator is also observed in episodic future thinking as it supports the intersection of functions like memory and affect. As we have observed with episodic and event cues, reward discounting is enhanced by the vmPFC's

connection with the MTL/hippocampus and the network involved in both episodic memory and future thinking. The vmPFC also has extensive connections with the amygdala, which is an important region of the brain implicated in the processing of emotions and rewards. Decision-making shares close proximity with emotional responding and previous studies have shown that the vmPFC may support emergent affective valuation of imagined experiences, thereby helping to mediate farsighted decisions (Benoit et al., 2014; Lin et al., 2015; Roy et al., 2012). The connection between the vmPFC and the amygdala is also sensitive to magnitude effect of reward choices, showing greater activity towards immediate reward responses over distant choices (Ludwig et al., 2015). Finally, the contributions of the vmPFC to reward valuation and reward discounting may also rely on its connections with other regions of the prefrontal cortex. Adaptive decision-making is modulated by the dlPFC in higher cognitive functions likes self-control, response inhibition, and working memory across situational contexts (Jimura et al., 2018; Schmidt et al., 2018). The value signals generated by the vmPFC may be modulated by the dlPFC at the time of choice and with increased preference for delayed rewards (Hare et al., 2014). Altogether, the weighing of delayed and risky reward choices may rely on a general reward valuation process involving the vmPFC and this can be further enhanced by considering other brain regions that are also implicated in decision-making. Our findings that schema instantiation may modulate reward discounting supports this idea and provides an example of one way in which the vmPFC involves other brain regions and integrates different functions to optimize decision-making.

Limitations

The studies described in this dissertation have advanced our understanding of how different forms of reward discounting relate to one another. To do so, I showed that they are

differentially affected by focal lesions to brain regions previously implicated in discounting and/or episodic future thinking and in healthy aging, which is also associated with a decline in episodic future thinking. However, interpretation of these findings is challenged by several limitations of these studies. During the cued conditions, participants were explicitly directed to imagine each of their future personal events for 10-15 seconds. During this time, participants were expected to be actively engaged in imagining specific details of each event, including who would be with them and what they would be doing, in all sensory modalities. However, this phase was self-paced, and it is impossible to determine whether all the participants were actively engaged throughout each imagining phase of the episodic cueing condition. The robust cueing effect observed in the delay discounting condition for healthy controls and the vmPFC patients suggests that this is likely the case, however. In the future, to ensure better reliability of the cues, additional manipulation checks could be incorporated into the task. For example, participants could be asked to verbalize their experiences during the cueing phase to maximize the attention and specificity of each cue at the start of the decision phase.

Another possible concern involves the different nature of the cues presented during the cueing conditions for the delay and probability discounting tasks in Study 2. For the probability discounting task, participants were asked to imagine personal, "timeless" events. Although episodic events by definition involve a scenario specific to a time and place, these instructions were motivated by a desire to mirror the delay discounting task but without a specified future time, even though a reward obviously would occur after the choice is made. Participants were instructed to think about an event in which a monetary reward is useful, regardless of whether it was in the past or the future. This might have limited the cues' meaningfulness, as the cues were not tied to a specific point in time. It should be noted, however, that this situation resembles the

situation in gambling (e.g., the purchase of lottery tickets), where people may or may not have ideas about the specific time when they would put any winnings to use. Nevertheless, in asking participants to describe a plausible event that is not constricted to a specific time, participants are not precluded from imagining a specific, singular event (e.g., buying ski equipment at the mall) or an "extended event" (e.g., a weekend ski trip in Vermont). Of course, these qualitative differences in cues may also exist for the more remote future time periods of the delay discounting task (e.g., travelling to Hong Kong with my grandchildren 10 years from now), and it may be presumed that differences in the self-generated cues will also generate differences in the way the cues are considered by the participants (e.g., in terms of phenomenological ratings). No statistically significant differences were found in the ratings between the cued delay and probability tasks, as evident in our findings, but only the cued delay discounting task produced a cueing effect. As a result, it remains unclear whether it was the nature of the cues, the nature of the decision-making task, or both that were responsible for the differences between the probability discounting and delay discounting tasks. That said, the procedure used still has considerable ecological validity.

It is possible that the risk aversion observed in the probability discounting task for vmPFC patients in Study 3 may actually be an artefact of the nature of their baseline impairment rather than the effect of personal event cues. In the uncued conditions, vmPFC patients produced much shallower discounting curves (i.e., more risk-taking) compared to healthy controls for probability discounting (Studies 1 and 2). It is possible that any type of manipulation could lead to changes to the discounting curve to reflect more normalized (steeper) discounting compared to their baseline. This differs from the controls (Study 2) and MTL patients (Study 3), who do not show overly steep or shallow discounting of probabilistic rewards and could have moved in

either direction following the presentation of cues. A similar issue may be encountered for delay discounting in vmPFC patients, which we saw in Study 1 as being steeper compared to controls. The shallower discounting observed in a previous paper following the presentation of event cues may also reflect the steeper baseline discounting of delayed rewards (Ciaramelli, De Luca, et al., 2021).

Another potential limitation for Study 3 is that most of the vmPFC patients were tested using a virtual online format as a consequence of the COVID-19 restrictions in Ontario. Although everything was done to ensure that the task replicated what would have typically been conducted if testing was in-person, including the presence of the experimenter through the use of screen-sharing, it is still possible that factors related to the testing environment may reduce the generalizability of the findings. For example, online testing may provide a different experience for vmPFC patients. During in-person testing, the physical presence of the researcher may increase social pressures to be less impulsive and more pragmatic. This phenomenon differs from demand characteristics typically described in the discounting literature, which argues that participants may infer the experiment's purpose and change their behaviours accordingly. Instead, participants may have a greater desire to make a positive impression during in-person testing compared to virtual testing. This possibility is unlikely in the current study, however, as our analyses did not reveal statistically significant differences between the discounting results for the virtual and in-person uncued condition.

The results of Study 3 also showed that the uncued, baseline condition of the probability discounting task replicated the findings in Study 1, whereas the novel, cued condition led to a decrease in risk-taking for the vmPFC patients. Unlike the MTL patients, who were tested before the pandemic, most of the vmPFC patients (other than J.A.G) were tested during the height of

COVID-19 and at a time when the province of Ontario was under strict lockdown restrictions that limited outdoor mobility. Undeniably, the pandemic has caused significant economic repercussions that have led to financial downturns. These diminishing economic opportunities greatly reduced financial flexibility during the pandemic, and, not surprisingly, also increased risk aversion amongst individuals with financial responsibility at stake (Heo, Rabbani, & Grable, 2021; Kluwe-Schiavon et al., 2021). Whether the steeper discounting observed in the majority of the vmPFC patients is due to the personal event cues or to the economic climate cannot be disentangled in the current study. Further testing, including administration of the virtual test format to healthy controls, may help to absolve concerns regarding any discrepancies in testing between the online and in-person format. Additionally, it may also be of interest to conduct a longitudinal study involving participants who were tested during the COVID-19 pandemic and after the lockdown restrictions have been eased to determine whether there may indeed be a cohort effect.

Finally, an additional limitation was the issue of the small patient sample size in Study 3, which was restricted by more challenging participant recruitment during the COVID-19 pandemic. Attempts to circumvent this issue was made by evaluating the patients in their respective groups, as well as the use of neuropsychological case study methods to evaluate individual differences within the patient groups. Nevertheless, given the heterogeneity of the lesions in our patient sample, replication studies with larger patient groups are recommended to confirm whether the dissociable results observed in the vmPFC and MTL groups are indeed reliable and to determine whether the results with the vmPFC patients does indeed link the vmPFC to schema-related processes involved in reward discounting.

Future Directions and Considerations

The current studies advance our understanding of the nature of delay and probability discounting, and the role of personal event cues, while pointing towards key brain regions that are involved in reward valuation and episodic thinking/schema instantiation. In the following sections, I outline important future directions and considerations for future research on these topics. I suggest modifications to personally relevant episodic cues used in reward discounting tasks and provide an overview of clinical implications for other populations of interest that were not studied in my dissertation. These considerations might further illuminate our understanding of the similarities and differences between delay and probability discounting, and the operation and utility of episodic event cues in optimizing reward discounting.

Manipulation of self-schema in healthy adults

The two studies employing personal event cues provided evidence that value-based decision-making may be reliant on schema-based memory and inferences. Similarly, a recent study by Vaidya and Badre (2020) found that vmPFC activity in healthy adults correlated with both experience- and schema-based values for participant decisions. How this strategy is specifically adopted to correct atypical reward discounting remains to be seen. Therefore, it could be that other forms of decisions (e.g., probability discounting) may still benefit from cues that improve self-schematic representation in healthy adults as we saw in Study 3 with the vmPFC patients. In Study 2, some participants commented that the cues were less personally meaningful and unrelated to the types of decisions that they were asked to make. This anecdotal evidence supports the idea that future studies looking at ways to directly manipulate the cues that would activate the self-schema during discounting tasks. For example, instead of using monetary rewards, as I have done in the current studies, participants may be asked to make choices based

on personally meaningful products or familiar items. Most studies investigating nonmonetary rewards have either used cross-commodity reward outcomes (e.g., an immediate monetary reward vs. a future nonmonetary reward) that may not fully capture the effects of delay discounting alone or have used nonmonetary objects that are not personally relevant (e.g., food, vouchers, cigarettes). Furthermore, most studies have found that nonmonetary rewards tend to be discounted more steeply than monetary rewards (see Odum et al., 2020 for a review). Cues that are more personally meaningful or sentimental (e.g., photographs, nostalgic experiences, heirlooms, or culturally meaningful items), on the other hand, may enhance valuation for both future- and risk-related rewards by evoking realism. Another way of manipulating self-schema may be to ask participants to think about their own self-characteristics prior to selecting their choices. For example, having individuals review personality traits may make the mental representation of themselves (i.e., their self-schema) more accessible, thereby encouraging greater depth of processing of their self-value that leads to advantageous decision-making (Wagner et al., 2012; Wu et al., 2017).

Specificity of the phenomenological ratings of personal event cues

The above section regarding future studies that can manipulate the cues to evoke self-schematic representation to enhance reward discounting also raises questions regarding the general nature of the cues provided by the participants. As per test instructions, care was taken to ensure that the cues generated by the participants were personally meaningful and represented a scenario where a monetary exchange is likely to occur. Nevertheless, certain cues may be more personally meaningful or salient to the participants than others, leading to individual differences in the choices made across different delayed periods or risky choice selections. As a result, individual cues may also be of qualitative interest due to possible differences in how

phenomenological features would be rated (e.g.,, vividness of the cue, *frequency* of imagining the cue during the task, and *emotional* attributes of the cue for the participants). In particular, these differences between individual cues would be interesting to explore with the vmPFC patients, who, as we discussed in Study 1, already show greater inconsistencies in responses compared to healthy controls and other patient groups. Preferential treatment for certain attributes has been described by Vaidya et al. (2017), suggesting that the vmPFC is involved in not only valuation judgement but the integration of higher-order information to promote optimal value judgement (see also Reber et al., 2017; Vaidya & Fellows, 2015; Yu et al., 2018). Thus, it would be of interest to equate discounting preferences across participants and at the level of each individual cue by controlling for the individual differences between cues. For example, a standard set of event cues could be pre-selected and rated for attributes that makes the cues more vivid or salient during imagination by a neutral participant group that would then be used by all the participants in the study.

Implications for healthy aging and focal lesion patients

Thus far, research on delay and probability discounting in cognitive neuroscience has largely focused on the vmPFC and MTL due to the contributions of these areas to episodic memory and future thinking. This is why individuals with damage to these key areas are subjects of the current dissertation. MTL patients who do not show modulatory effects to delay discounting after being presented with personally meaningful event cues can, nonetheless, show reduced discounting when given cues that elicit semantic representations of the future time period in which they will receive the reward (Palombo et al., 2016). Past research has shown that personal semantic content is likely integrated within future autobiographical event representations (Devitt et al., 2017; Irish et al., 2012; 2016; Wang et al., 2016), and both

neuroimaging and patient-lesion studies have pointed to reliance on semantic processes during the simulation of novel events that may be above and beyond episodic memory content (Devitt et al., 2017; Strikwerda-Brown et al., 2020; see Schacter & Addis, 2020, for a review). Older adults, such as those described in Study 2, often have high variability in age-related cognitive decline to episodic memory function (Nyberg et al., 2012) and this may lead to similar reliance on semantic content during decision-making. Although a recent study by Lempert et al. (2020) found only perceptually-rich episodic content to be associated with intertemporal choice and not external details, future studies could aim to elucidate these differences by evaluating other forms of reward discounting in both healthy aging and patient-lesion populations. As a follow-up to the findings described in this dissertation, older adults could also undergo neuroimaging while completing cued discounting tasks to see if, indeed, changes to hippocampal function are responsible for the dampened episodic imagining effect.

Consideration of other neurological clinical populations

The condition of semantic variant primary progressive aphasia (semantic dementia), a form of frontotemporal dementia, may be of interest when investigating potential semantic strategies used during delay and probability discounting. These patients have specific deficits with future thinking while episodic memory remains largely intact (Irish et al., 2012). Furthermore, semantic dementia patients have noted behavioural abnormalities, such as rigidity in routines and behaviours, that are suggestive of impairments to time perception and organization that may lead to a greater likelihood for impulsive, present-biased choice selection (Irish et al., 2012; Snowden et al., 2001). These observations support the findings by Chiong et al. (2016) who recently found semantic dementia patients to discount delayed rewards more steeply than controls and a comparative behavioural-variant frontotemporal dementia patient

group. A follow-up to this study could compare semantic dementia patients to patient populations that show similar performance to vmPFC patients (due to focal lesions or behavioural variant frontotemporal dementia). These patient groups could be assessed on tests of probability discounting to determine whether they would show similar benefits from personal event cues for both delay and probability discounting.

Another neurological patient population that may be of interest is individuals with Parkinson's disease (PD). The pathological hallmark of PD is a loss of dopaminergic innervation of the basal ganglia. Alongside the MTL, the basal ganglia play a fundamental role in learning and memory. Whereas the MTL is extensively studied for its role in rapid relational learning (i.e., declarative memory), the basal ganglia have been studied for habitual and procedural learning due to its contributions to stimulus-response associations and feedback-based learning. The basal ganglia also make important contributions to value-based decision-making due to its proximity to the vmPFC (Haber & Knutson, 2010) and its involvement in the dopaminergic system that plays a critical role in modulating behavioural sensitivity (Foerde & Shohamy, 2011; Schultz, 2007). Much of this evidence comes from studies of PD patients that have a pathological hallmark of extensive loss of dopaminergic innervation of the basal ganglia. PD patients experience cognitive deficits during the course of the disease that is specifically attributed to the loss of dopamine neurons (Foerde & Shohamy, 2011; Sharp et al., 2016). These dopamine-dependent deficits lead to difficulties in using reward information to guide both learning and subsequent decision-making (Grogan et al., 2017; Sharp et al., 2016; McCoy et al., 2019). Although treatment of PD typically involves dopamine replacement therapy, this too can alter the reward responses typically associated with functional basal ganglion (McCoy et al., 2019; Muhammed et al., 2016; Sharp et al., 2020). Overdosing effects can frequently occur,

leading to progressive dysfunction of the striatum within the basal ganglia and cognitive impairments related to executive control and reward-based motivation. PD patients often develop impulsive-compulsive disorder, which can manifest as stereotypical, repetitive motoric behaviours, appetitive behaviours, and disinhibition (e.g., hypersexuality, pathological gambling and risk-taking; Cools, 2006; Voon & Fox, 2007). These individuals also show steep delay discounting (Housden et al., 2010; Milenkova et al., 2011) and would also likely show impaired decision-making for risky rewards due to well documented impairments to probabilistic learning (Knowlton et al., 1996; Siegert et al., 2006). Targeted therapeutic interventions could be developed to address impulsivity and assist in reward valuation. Similar to healthy older adults, cued delay discounting has been suggested as a form of intervention that could be modified to train PD patients to minimize impulsive choices by learning to recognize intertemporal choice contexts (e.g., delaying gratification for more optimal reward choices; Rung & Madden, 2019). A secondary element is the adaptation of the delay discounting task to assess individuals who experience motoric difficulties (i.e., PD). Frost and McNaughton (2017) proposed that the basal ganglia, which is primarily involved in motor control, may be part of a decision-making subsystem that is activated to produce or suppress a motor output response when a decision involving a target gain is being considered. In a decision-making task, this subsystem may be involved in the motor control used to press a lever/button or giving a verbal response. Alternatively, it may also be involved in situations where inappropriate motor responses need to be withheld or suppressed in order to obtain the desired gain (e.g., suppress the urge to obtain the immediate, smaller reward and wait for the larger, later option; Eagle & Baunez, 2010). Thus, delay discounting tasks administered to individuals with PD could advantageously involve both

motor (button press) and nonmotor (verbal response) outputs when making the decision (Frost & McNaughton, 2017).

Consideration for non-neurological clinical populations

Findings of opposite weightings for immediacy (delay discounting) and likelihood (probability discounting) in vmPFC patients provides evidence supporting the complexity of measuring impulsivity (Duckworth & Kern, 2011). Nevertheless, laboratory-based reward discounting tasks have potential as tools to elucidate and better understand the underlying neurocircuitry involved in other clinical (psychiatric) populations that also exhibit impulsive behaviours and reward valuation impairments. The vmPFC, which is involved in coordinating flexible behaviour and reward valuation, is thought to play a critical role in anxiety disorders (Myers-Schulz & Koenigs, 2012). Patients diagnosed with obsessive-compulsive disorder (OCD), for example, show increased vmPFC activity at rest (Whiteside et al., 2004) but impaired activity during error processing and learning of differentiable threat outcomes (Stern et al., 2011; Apergis-Schoute et al., 2017). Interestingly enough, however, these individuals do not differ from healthy controls in delay discounting (e.g., Steinglass et al., 2017; Carlisi et al., 2017). These mixed findings may shed light on dimensional differences between the dysregulated processes observed in psychiatric conditions like OCD compared to individuals with focal brain lesions who have much more specific impairments.

Given the modulatory benefits that episodic cues have shown in vmPFC patients to reduce risk-taking and impulsive reward choices, it is possible that the manipulation of reward discounting through event cues could also be applicable to other non-neurological populations in which impulsivity tends to be an impairment. The presentation of episodic future thinking and event cues during delay discounting has already been implemented in the treatment of substance

abuse, such as for alcohol, (Snider et al., 2016), cigarettes (Stein et al., 2018), and cocaine use (Forster et al., 2021). Further research will need to be conducted to see how reward discounting tasks can be modified to differentiate between populations that delay rewards pathologically (e.g., anorexia nervosa) and those that increase the discounting of rewards substantially (e.g., schizophrenia).

Delay and probabilistic losses

The puzzle of opposite effects of vmPFC lesions on the relative weighting of reward amount remains, but one implication is that consideration of the integration of other outcome attributes, perhaps most prominently losses (Estle et al., 2019), may shed light on specialized integration functions in general. Discounting of delayed or probabilistic losses is an interesting topic that remains to be explored in relation to the effects of personal event cues in young and older adults and in individuals with focal lesions. Despite the many everyday decisions that we make that require the consideration of losses (e.g., repaying all your student loans upfront or paying in increments while accruing interest), the discounting literature remains focused on the discounting of (delayed or probabilistic) gains. Discounting of gains and losses share similar mathematical properties (akin to delay and probability discounting), though they also differ in fundamental attributes. For example, both delayed and probabilistic losses are commonly discounted at a lower rate than delayed and probabilistic gains of the same reward value (known as a sign effect; Benzio et al., 1989; Estle et al., 2006; Yeh et al., 2020).

The reward amount also appears to distinguish losses from gains. Previous findings have shown that while the discounting of delayed and probabilistic gains leads to a magnitude effect, losses remain relatively immune to fluctuations in reward amount (Green, Myerson, Oliveira, & Chang, 2014; Myerson et al., 2011). Taken together, Estle et al. (2006) found that magnitude

effects led to delayed gains being discounted more steeply than losses, but only with smaller reward amounts. In contrast, probabilistic gains were discounted more steeply than probabilistic losses, but only when making selections between larger reward amounts (see also Estle et al., 2019). Given the differences in baselines, it would be of theoretical interest to see whether personal event cues would still modulate discounting for both delayed and probabilistic rewards, and in which direction. At least for larger probabilistic losses, control participants engaged in episodic future thinking may respond more steeply as a result of the shallow "ceiling effect" observed in the standard condition. It would be of interest to observe the response patterns of the vmPFC patients to see whether their shallow probabilistic gains would be matched by equally shallow or shallower (i.e., riskier) preference to avoid losing rewards. Finally, losses also appear to be more susceptible to individual differences in discounting compared to gains (Myerson et al., 2017; Yeh et al., 2020), which may be of important consequence when addressing our previous discussions about the saliency and nature of specific cues.

Conclusion

My dissertation examined similarities and differences in delay and probability discounting across three studies, focusing on the modulatory effects that episodic and personally meaningful event cues may have on both future and risky rewards for healthy young and older adults and individuals with focal lesions. Importantly, these studies identified the vmPFC as a critical region of the brain involved in reward valuation, episodic simulation of future and novel experiences, and, potentially, schematic representations of the self. Furthermore, the findings emphasize the multifaceted nature of different forms of discounting and of the function of the vmPFC, a thesis that forms the backbone of the late Donald Stuss's general approach to the medial prefrontal cortex (Stuss et al., 2005; Stuss, 2006; Stuss & Levine, 2002; Stuss, 2017).

Additional evidence is required to establish whether or not the subjective valuation view of vmPFC function(s) is correct, and how to account for the apparent paradox of differential weighting of reward amount and dissociable effects of episodic cueing following vmPFC lesions. In the absence of an alternative explanation for why focal lesions of the vmPFC would have opposite effects on the weighting of amount relative to other reward attributes (e.g., immediacy, likelihood, episodic imagining), the present findings suggest that these are two distinct functions, affirming previous findings in the literature suggesting that there is no unitary trait or mechanism underlying reward discounting. Why and how these functions are differentially affected by vmPFC lesions remains to be understood, though my dissertation brings forth the possibility that a common strategy, and not a common mechanism, may hold the answer to these questions.

Nevertheless, whether a multifunctional view or an integrative framework involving a schematic instantiation strategy best explains the issues addressed by the examination of delay and probability discounting in the studies discussed, these issues are all fundamentally important and have implications for our understanding of both the vmPFC and decision-making itself. Although considerable effort, both experimental and theoretical, may be required to resolve these issues now and in future studies, the fundamental nature of these issues justified the effort to pursue and complete the research studies in my dissertation.

References

Abela, A. R., & Chudasama, Y. (2013). Dissociable contributions of the ventral hippocampus and orbitofrontal cortex to decision-making with a delayed or uncertain outcome. *European Journal of Neuroscience*, *37*, 640–647. https://doi.org/10.1111/ejn.12071

Addis, D. R. (2020). Mental Time Travel? A Neurocognitive Model of Event Simulation. *Review of Philosophy and Psychology*, *11*, 233–259. https://doi.org/10.1007/s13164-020-00470-0

Addis, D. R., Pan, L., Vu, M. A., Laiser, N., & Schacter, D. L. (2009). Constructive episodic simulation of the future and the past: Distinct subsystems of a core brain network mediate imagining and remembering. *Neuropsychologia*, *47*, 2222–2238. https://doi.org/10.1016/j.neuropsychologia.2008.10.026

Addis, D. R., Musicaro, R., Pan, L., & Schacter, D. L. (2010). Episodic simulation of past and future events in older adults: Evidence from an experimental recombination task. *Psychology and Aging*, *25*, 369–376. https://doi.org/10.1037/a0017280

Addis, D. R., Wong, A. T., & Schacter, D. L. (2007). Remembering the past and imagining the future: Common and distinct neural substrates during event construction and elaboration. *Neuropsychologia*, *45*, 1363–1377. https://doi.org/10.1016/j.neuropsychologia.2006.10.016

Addis, D. R., Wong, A. T., & Schacter, D. L. (2008). Age-related changes in the episodic simulation of future events. *Psychological Science*, *19*, 33–41. https://doi.org/10.1111/j.1467-9280.2008.02043.x

American Psychiatric Association. (2000). *Diagnostic and statistical manual of mental disorders* (4th ed., text rev.). Washington, DC: APA.

American Psychiatric Association. (2013*). Diagnostic and statistical manual of mental disorders* (5th ed.). Arlington, VA: American Psychiatric Publishing.

Apergis-Schoute, A. M., Gillan, C. M., Fineberg, N. A., Fernandez-Egea, E., Sahakian, B. J., & Robbins, T. W. (2017). Neural basis of impaired safety signaling in obsessive compulsive disorder. *Proceedings of the National Academy of Sciences, 114,* 3216-3221. https://doi.org/10.1073/pnas.1609194114

Appelhans, B. M., Woolf, K., Pagoto, S. L., Schneider, K. L., Whited, M. C., & Liebman, R. (2011). Inhibiting food reward: Delay discounting, food reward sensitivity, and palatable food intake in overweight and obese women. *Obesity, 19*, 2175–2182. https:// doi.org/10.1038/oby.2011.57

Manuel, A.L., Murray, N.W.G. & Piguet, O. (2019). Transcranial direct current stimulation (tDCS) over vmPFC modulates interactions between reward and emotion in delay discounting. *Scientific Reports,* 18735. https://doi.org/10.1038/s41598-019-55157-z

Ballard, I. C., Aydogan, G., Kim, B., & McClure, S. M. (2018). Causal Evidence for the Dependence of the Magnitude Effect on Dorsolateral Prefrontal Cortex. *Scientific Reports*, *8*, 1–8. https://doi.org/10.1038/s41598-018-34900-y

Bar, M. (2010). Wait for the Second Marshmallow? Future-Oriented Thinking and Delayed Reward Discounting in the Brain. *Neuron*, *66*, 4–5. https://doi.org/10.1016/j.neuron.2010.04.001

Barry, D. N., Barnes, G. R., Clark, I. A., & Maguire, E. A. (2019). The neural dynamics of novel scene imagery. *Journal of Neuroscience*, *39*, 4375–4386. https://doi.org/10.1523/JNEUROSCI.2497-18.2019

Bartra, O., McGuire, J. T., & Kable, J. W. (2007). The valuation system: A coordinate-based meta-analysis of BOLD fMRI experiments examining neural correlates of subjective value. *NeuroImage*, *76*, 412–427. https://doi.org/10.1016/j.neuroimage.2013.02.063

Baumeister, R. F., Masicampo, E. J., & Vohs, K. D. (2011). Do conscious thoughts cause behavior? *Annual Review of Psychology, 62*, 331–361. https://doi.org/10.1146/annurev.psych.093008.131126

Bechara, A. (2005). Decision making, impulse control and loss of willpower to resist drugs: A neurocognitive perspective. *Nature Neuroscience, 8*, 1458–1463. https://doi.org/10.1038/nn1584

Bechara, A. (2011) The somatic marker hypothesis and its neural basis: Using past experiences to forecast the future in decision making. In M. Bar (Ed.), Predictions in the brain using our past to generate a future (pp. 122–133). New York: Oxford University Press. https://doi.org/10.1093 /acprof:oso/9780195395518.003.0048

Bechara, A., Damasio, A. R., Damasio, H., & Anderson, S. W. (1994). Insensitivity to future consequences following damage to human prefrontal cortex. *Cognition, 50*, 7-15. https://doi.org/10.1016/0010-0277(94)90018-3

Bechara, A., Tranel, D., Damasio, H., & Damasio, A. R. (1996). Failure to respond autonomically to anticipated future outcomes following damage to prefrontal cortex. *Cerebral Cortex, 6*, 215–225. https://doi.org/10.1093/cercor/6.2 .215

Bechara, A., Tranel, D., & Damasio, H. (2000). Characterization of the decision-making impairment of patients with bilateral lesions of the ventromedial prefrontal cortex. *Brain, 123*, 2189–2202. https://doi.org/10.1093/brain/123.11.2189

Bell, D. E. (1982). Regret in decision making under uncertainty. *Operations Research, 30*, 961–981. https://doi.org/10 .1287/opre.30.5.961

Bellana, B., Liu, Z. X., Diamond, N. B., Grady, C. L., & Moscovitch, M. (2017). Similarities and differences in the default mode network across rest, retrieval, and future imagining. *Human*

Brain Mapping, *38*, 1155–1171. https://doi.org/10.1002/HBM.23445

Benoit, R. G., Berkers, R. M. W. J., & Paulus, P. C. (2018). An adaptive function of mental time travel: Motivating farsighted decisions. *Behavioral and Brain Sciences*, *41*, 17–18. https://doi.org/10.1017/S0140525X1700125X

Benoit, R. G., Gilbert, S. J., & Burgess, P. W. (2011). A neural mechanism mediating the impact of episodic prospection on farsighted decisions. *The Journal of Neuroscience : The Official Journal of the Society for Neuroscience*, *31*, 6771–6779. https://doi.org/10.1523/JNEUROSCI.6559-10.2011

Benoit, R. G., & Schacter, D. L. (2015). Specifying the core network supporting episodic simulation and episodic memory by activation likelihood estimation. *Neuropsychologia*, *75*, 450–457. https://doi.org/10.1016/j.neuropsychologia.2015.06.034

Benoit, R. G., Szpunar, K. K., & Schacter, D. L. (2014). Ventromedial prefrontal cortex supports affective future simulation by integrating distributed knowledge. *Proceedings of the National Academy of Sciences*, *111*, 16550–16555. https://doi.org/10.1073/pnas.1419274111

Benzion, U., Rapoport, A., & Yagil, J. (1989). Discount Rates Inferred from Decisions: An Experimental Study. *Http://Dx.Doi.Org/10.1287/Mnsc.35.3.270*, *35*, 270–284.

Bertossi, E., Aleo, F., Braghittoni, D., & Ciaramelli, E. (2016). Stuck in the here and now: Construction of fictitious and future experiences following ventromedial prefrontal damage. *Neuropsychologia*, *81*, 107–116. https://doi.org/10.1016/j.neuropsychologia.2015.12.015

Bertossi, E., Tesini, C., Cappelli, A., & Ciaramelli, E. (2016). Ventromedial prefrontal damage causes a pervasive impairment of episodic memory and future thinking. *Neuropsychologia*, *90*, 12–24. https://doi.org/10.1016/j.neuropsychologia.2016.01.034

Bettio, L. E. B., Rajendran, L., & Gil-Mohapel, J. (2017). The effects of aging in the hippocampus and cognitive decline. *Neuroscience and Biobehavioral Reviews, 79,* 66–86. https://doi.org/10.1016/j.neubiorev.2017.04.030

Białaszek, W., Ostaszewski, P., Green, L., & Myerson, J. (2019). On Four Types of Devaluation of Outcomes Due to Their Costs: Delay, Probability, Effort, and Social Discounting. *The Psychological Record, 69,* 415–424. https://doi.org/10.1007/s40732-019-00340-x

Bickel, W. K., Pitcock, J. A., Yi, R., & Angtuaco, E. J. (2009). Congruence of BOLD response across intertemporal choice conditions: Fictive and real money gains and losses. *Journal of Neuroscience, 29,* 8839–8846. https://doi.org/10.1523/ JNEUROSCI.5319-08.2009

Blankenstein, N. E., Peper, J. S., Crone, E. A., & van Duijvenvoorde, A. C. K. (2017). Neural mechanisms underlying risk and ambiguity attitudes. *Journal of Cognitive Neuroscience, 29,* 1845–1859. https://doi.org/10.1162/jocn_a_01162

Boorman, E. D., Rushworth, M. F., & Behrens, T. E. (2013). Ventromedial prefrontal and anterior cingulate cortex adopt choice and default reference frames during sequential multi-alternative choice. *Journal of Neuroscience, 33,* 2242–2253. https://doi.org/10.1523/ JNEUROSCI.3022-12.2013

Boyer, P. (2008). Evolutionary economics of mental time travel? *Trends in Cognitive Sciences, 12,* 219–224. https://doi.org/10.1016/j.tics.2008.03.003

Bray, S., Shimojo, S., & O'Doherty, J. P. (2010). Human medial orbitofrontal cortex is recruited during experience of imagined and real rewards. *Journal of Neurophysiology, 103,* 2506–2512. https://doi.org/10.1152/jn.01030.2009

Bromberg, U., Wiehler, A., & Peters, J. (2015). Episodic future thinking is related to impulsive decision making in healthy adolescents. *Child Development, 86*, 1458–1468. https://doi.org/10.1111/cdev.12390

Bromberg, U., Lobatcheva, M., & Peters, J. (2017). Episodic future thinking reduces temporal discounting in healthy adolescents. *PLoS One, 12*, e0188079. https://doi. org/10.1371/journal.pone.0188079

Brown, J. W., & Alexander, W. H. (2017). Foraging Value, Risk Avoidance, and Multiple Control Signals: How the Anterior Cingulate Cortex Controls Value-based Decision-making. *Journal of Cognitive Neuroscience, 29*, 1656–1673. https://doi.org/10.1162/jocn_a_01140

Buckner, R. L., & Carroll, D. C. (2007). Self-projection and the brain. *Trends in Cognitive Sciences, 11*, 49–57. https://doi.org/10.1016/j.tics.2006.11.004

Bulley, A., & Gullo, M. J. (2017). The influence of episodic foresight on delay discounting and demand for alcohol. *Addictive Behaviors, 66*, 1–6. https://doi.org/10.1016/j. addbeh.2016.11.003

Bulley, A., Henry, J., & 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*, 29–47. https://doi.org/http://dx.doi.org/10.1037/gpr0000061

Bulley, A., & Schacter, D. L. (2020). Deliberating trade-offs with the future. *Nature Human Behaviour, 4*, 238–247. https://doi.org/10.1038/s41562-020-0834-9

Cabeza, R., & Dennis, N. A. (2013). Frontal lobes and aging: Deterioration and compensation. In D. T. Stuss, & R. T. Knight (Eds.). *Principles of frontal lobe function (2nd ed.)* (pp. 628–

652). New York: Oxford University Press. https://doi.org/10.1093/med/9780199837755.003.0044

Calvert, A. L., Green, L., & Myerson, J. (2011). Discounting in pigeons when the choice is between two delayed rewards: Implications for species comparisons. *Frontiers in Neuroscience*. https://doi.org/10.3389/fnins.2011.00096

Camille, N., Coricelli, G., Sallet, J., Pradat-Diehl, P., Duhamel, J. R., & Sirigu, A. (2004). The involvement of the orbitofrontal cortex in the experience of regret. *Science, 304*, 1167–1170. https://doi.org/10.1126/science.1094550

Campbell, K. L., Madore, K. P., Benoit, R. G., Thakral, P. P., & Schacter, D. L. (2018). Increased hippocampus to ventromedial prefrontal connectivity during the construction of episodic future events. *Hippocampus, 28*, 76. https://doi.org/10.1002/HIPO.22812

Carlisi, C. O., Norman, L. J., Lukito, S. S., Radua, J., Mataix-Cols, D., & Rubia, K. (2017). Comparative multimodal meta-analysis of structural and functional brain abnormalities in autism spectrum disorder and obsessive-compulsive disorder. *Biological Psychiatry*, *82*, 83-102.

Caruso, E. M., Gilbert, D. T., & Wilson, T. D. (2008). A Wrinkle in time: Asymmetric valuation of past and future events. *Psychological Science*, *19*, 796–801. https://doi.org/10.1111/j.1467-9280.2008.02159.x

Carstensen, L. L., Isaacowitz, D. M., & Charles, S. T. (1999). Taking time seriously: A theory of socioemotional selectivity. *American Psychologist, 54*, 165–181. https://doi.org/10.1037/0003-066X.54.3.165

Chao, L.-W., Szrek, H., Pereira, N. S., & Pauly, M. V. (2009). Time preference and its relationship with age, health, and survival probability. *Judgment and Decision Making, 4*, 1–19.

Charlton, S. R., & Fantino, E. (2008). Commodity specific rates of temporal discounting: Does metabolic function underlie differences in rates of discounting? In: *Behavioural Processes, 77*, 334–342. https://doi.org/10.1016/j.beproc.2007.08.002

Cheng, Y. Y., Shein, P. P., & Chiou, W. B. (2012). Escaping the impulse to immediate gratification: The prospect concept promotes a future-oriented mindset, prompting an inclination towards delayed gratification. *British Journal of Psychology, 103*, 129–141. https://doi.org/10.1111/j.2044-8295.2011.02067.x.

Chhatre, S., Cook, R., Mallik, E., & Jayadevappa, R. (2017). Trends in substance use admissions among older adults. *BMC Health Services Research, 17*, 1–8. https://doi. org/10.1186/s12913-017-2538-z. Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum Associates, Publishershttps://doi.org/10.4324/ 9780203771587

Chiong, W., Wood, K. A., Beagle, A. J., Hsu, M., Kayser, A. S., Miller, B. L., & Kramer, J. H. (2016). Neuroeconomic dissociation of semantic dementia and behavioural variant frontotemporal dementia. *Brain, 139*, 578–587. https://doi.org/10.1093/brain/awv344

Ciaramelli, E., Anelli, F., & Frassinetti, F. (2021). An asymmetry in past and future mental time travel following vmPFC damage. *Social Cognitive and Affective Neuroscience*, *16*, 315–325. https://doi.org/10.1093/scan/nsaa163

Ciaramelli, E., De Luca, F., Kwan, D., Mok, J., Bianconi, F., Knyagnytska, V., Craver, C., Green, L., Myerson, J., & Rosenbaum, R. S. (2021). The role of ventromedial prefrontal

cortex in reward valuation and future thinking during intertemporal choice. *eLife*.

Ciaramelli, E., De Luca, F., Monk, A. M., McCormick, C., & Maguire, E. A. (2019). What "wins" in VMPFC: Scenes, situations, or schema? *Neuroscience and Biobehavioral Reviews*, *100*, 208–210. https://doi.org/10.1016/j.neubiorev.2019.03.001

Clairis, N., & Pessiglione, M. (2020). Value, confidence and deliberation in preference tasks: A triple dissociation in the medial prefrontal cortex. *bioRxiv*. https://doi.org/10 .1101/2020.09.17.301291

Clark, L., Bechara, A., Damasio, H., Aitken, M. R. F., Sahakian, B. J., & Robbins, T. W. (2008). Differential effects of insular and ventromedial prefrontal cortex lesions on risky decision-making. *Brain*, *131*, 1311–1322. https://doi.org/10.1093/brain/awn066

Clithero, J. A., & Rangel, A. (2014). Informatic parcellation of the network involved in the computation of subjective value. *Social Cognitive and Affective Neuroscience*, *9*, 1289–1302. https://doi.org/10.1093/SCAN/NST106

Cools, R. (2006). Dopaminergic modulation of cognitive function-implications for L-DOPA treatment in Parkinson's disease. *Neuroscience and Biobehavioral Reviews*, *30*, 1–23. https://doi.org/10.1016/j.neubiorev.2005.03.024

Craver, C. F., Kwan, D., Steindam, C., & Rosenbaum, R. S. (2014). Individuals with episodic amnesia are not stuck in time. *Neuropsychologia*, *57*, 191–195. https://doi.org/10.1016/j.neuropsychologia.2014.03.004

Crawford, J. R., Garthwaite, P. H., & Porter, S. (2010). Point and interval estimates of effect sizes for the case-controls design in neuropsychology: Rationale, methods, implementations, and proposed reporting standards. *Cognitive Neuropsychology*, *27*, 245–260. https://doi.org/10.1080/02643294.2010.513967

D'Argembeau, A. (2020). Zooming in and out on one's life: Autobiographical representations at multiple time scales. *Journal of Cognitive Neuroscience, 32,* 2037–2055. https://doi.org/10.1162/jocn_a_01556

D'Argembeau, A., Jedidi, H., Balteau, E., Bahri, M., Phillips, C., & Salmon, E. (2012). Valuing one's self: medial prefrontal involvement in epistemic and emotive investments in self-views. *Cerebral Cortex, 22,* 659–67. https://doi.org/10.1093/cercor/bhr144

D'Argembeau, A., & Mathy, A. (2011). Tracking the Construction of Episodic Future Thoughts. *Journal of Experimental Psychology: General, 140,* 258–271. https://doi.org/10.1037/a0022581

D'Argembeau, A., & Salmon, E. (2012). The neural basis of semantic and episodic forms of self-knowledge: Insights from functional neuroimaging. *Advances in Experimental Medicine and Biology, 739,* 276–290. https://doi.org/10.1007/978-1-4614-1704-0_18

D'Argembeau, A., Stawarczyk, D., Majerus, S., Collette, F., Van der Linden, M., Feyers, D., Maquet, P., & Salmon, E. (2010). The Neural Basis of Personal Goal Processing When Envisioning Future Events. *Journal of Cognitive Neuroscience, 22,* 1701–1713. https://doi.org/10.1162/JOCN.2009.21314

Daniel, T. O., Said, M., Stanton, C. M., & Epstein, L. H. (2015). Episodic future thinking reduces delay discounting and energy intake in children. *Eating Behaviors, 18,* 20–24. https://doi.org/10.1016/j.eatbeh.2015.03.006

Dassen, F. C., Jansen, A., Nederkoorn, C., & Houben, K. (2016). Focus on the future: Episodic future thinking reduces discount rate and snacking. *Appetite, 96,* 327–332. https://doi.org/10.1016/j.appet.2015.09.032

De Luca, F., Benuzzi, F., Bertossi, E., Braghittoni, D., di Pellegrino, G., & Ciaramelli, E. (2018).

Episodic future thinking and future-based decision-making in a case of retrograde amnesia. *Neuropsychologia, 110,* 92–103. https://doi.org/10.1016/j.neuropsychologia.2017.08.007

Denny, B. T., Kober, H., Wager, T. D., & Ochsner, K. N. (2012). A Meta-analysis of Functional Neuroimaging Studies of Self- and Other Judgments Reveals a Spatial Gradient for Mentalizing in Medial Prefrontal Cortex. *Journal of Cognitive Neuroscience, 24*, 1742–1752. https://doi.org/10.1162/JOCN_A_00233

Devitt, A. L., Addis, D. R., & Schacter, D. L. (2017). Episodic and semantic content of memory and imagination: A multilevel analysis. *Memory & Cognition, 45,* 1078–1094. https://doi.org/10.3758/s13421-017-0716-1

Diekhof, E. K., Kaps, L., Falkai, P., & Gruber, O. (2012). The role of the human ventral striatum and the medial orbitofrontal cortex in the representation of reward magnitude-An activation likelihood estimation meta-analysis of neuroimaging studies of passive reward expectancy and outcome processing. *Neuropsychologia, 50,* 1252-1266. https://doi.org/10.1016/j.neuropsychologia.2012.02.007

Duckworth, A. L., & Kern, M. L. (2011). A meta-analysis of the convergent validity of self-control measures. *Journal of Research in Personality, 45*, 259-268. https://doi.org/10.1016/j.jrp.2011.02.004

Eagle, D. M., & Baunez, C. (2010). Is there an inhibitory-response-control system in the rat? Evidence from anatomical and pharmacological studies of behavioral inhibition. *Neuroscience and Biobehavioral Reviews, 34*, 50–72. https://doi.org/10.1016/j.neubiorev.2009.07.003

Engelmann, J. B., & Tamir, D. (2009). Individual differences in risk preference predict neural responses during financial decision-making. *Brain Research, 1290,* 28–51.

https://doi.org/10.1016/j.brainres.2009.06.078

Estle, S. J., Green, L., & Myerson, J. (2019). When immediate losses are followed by delayed gains: Additive hyperboloid discounting models. *Psychonomic Bulletin & Review, 26,* 1418–1425. https://doi.org/10.3758/S13423-019-01599-5

Estle, S. J., Green, L., Myerson, J., & Holt, D. D. (2007). Discounting of Monetary and Directly Consumable Rewards.pdf. *Psychological Science, 18,* 58–63. https://doi.org/10.1111/j.1467-9280.2007.01849.x

Fellows, L. K. (2011). Orbitofrontal contributions to value-based decision making: Evidence from humans with frontal lobe damage. *Annals of the New York Academy of Sciences, 1239,* 51–58. https://doi.org/10.1111/j.1749-6632.2011.06229.x

Fellows, L. K., & Farah, M. J. (2005). Dissociable elements of human foresight: A role for the ventromedial frontal lobes in framing the future, but not in discounting future rewards. *Neuropsychologia, 43,* 1214–1221. https://doi.org/10.1016/j.neuropsychologia.2004.07.018

Fellows, L. K., & Farah, M. J. (2007). The role of ventromedial prefrontal cortex in decision making: Judgment under uncertainty or judgment per se? *Cerebral Cortex, 17,* 2669–2674. https://doi.org/10.1093/cercor/bhl176

Floden, D., Alexander, M. P., Kubu, C. S., Katz, D., & Stuss, D. T. (2008). Impulsivity and risk-taking behavior in focal frontal lobe lesions. *Neuropsychologia, 46,* 213–223. https://doi.org/10.1016/j.neuropsychologia.2007.07.020

Foerde, K., & Shohamy, D. (2011). The role of the basal ganglia in learning and memory: insight from Parkinson's disease. *Neurobiology of Learning and Memory, 96,* 624-636. https://doi.org/10.1016/j.nlm.2011.08.006

Forster, S. E., Steinhauer, S. R., Ortiz, A., & Forman, S. D. (2021). Evaluating effects of

episodic future thinking on valuation of delayed reward in cocaine use disorder: a pilot study. *The American Journal of Drug and Alcohol Abuse*, *47*, 199-208.

Frost, R., & McNaughton, N. (2017). The neural basis of delay discounting: A review and preliminary model. *Neuroscience and Biobehavioral Reviews*, *79*, 48–65. https://doi.org/10.1016/j.neubiorev.2017.04.022

Gaesser, B., Sacchetti, D. C., Addis, D. R., & Schacter, D. L. (2011). Characterizing Age-Related Changes in Remembering the Past and Imagining the Future. *Psychology and Aging*, *26*(1), 80–84. https://doi.org/10.1037/a0021054

Gao, A. F., Keith, J. L., Gao, F. Q., Black, S. E., Moscovitch, M., & Rosenbaum, R. S. (2020). Neuropathology of a remarkable case of memory impairment informs human memory. *Neuropsychologia*, *140*, 107342. https://doi.org/10.1016 /j.neuropsychologia.2020.107342

George, L. K., & Ferraro, K. F. (2016). Aging and the Social Sciences: Progress and Prospects. In L. K. George, & K. F. Ferraro (Eds.). *Handbook of Aging and the Social Sciences* (pp. 3–22). (Eighth Ed.). San Diego: Elsevier Academic Press. https://doi. org/10.1016/B978-0-12-417235-7.00001-9

Ghosh, V. E., Moscovitch, M., Colella, B. M., & Gilbo, A. (2014). Schema representation in patients with ventromedial PFC lesions. *Journal of Neuroscience*, *34*, 12057–12070. https://doi.org/10.1523/JNEUROSCI.0740-14.2014

Gilbert, D. T., & Wilson, T. D. (2007). Prospection: Experiencing the future. *Science*, *317*, 1351–1354. https://doi.org/10 .1126/science.1144161

Gilboa, A., & Marlatte, H. (2017). Neurobiology of schemas and schema-mediated memory. *Trends in Cognitive Sciences*, *21*, 618–631. https://doi.org/10.1016/j.tics.2017.04.013

Green, L., Fry, A. F., & Myerson, J. (1994). Discounting of delayed rewards: A life-span comparison. *Psychological Science, 5,* 33–36. https://doi.org/10.1111/j.1467-9280.1994.tb00610.x

Green, L., & Myerson, J. (1996). Exponential versus hyperbolic discounting of delayed outcomes: Risk and waiting time. *American Zoologist, 36,* 496–505. https://doi.org/10.1093/icb/36.4.496

Green, L., & Myerson, J. (2004). A Discounting Framework for Choice With Delayed and Probabilistic Rewards. *Psychological Bulletin*, *130*, 769–792. https://doi.org/10.1037/0033-2909.130.5.769

Green, L., & Myerson, J. (2010). Experimental and correlational analyses of delay and probability discounting. In G. J. Madden & W. K. Bickel (Eds.), *Impulsivity: The behavioral and neurological science of discounting* (pp. 67–92). American Psychological Association. https://doi.org/10.1037 /12069-003

Green, L., & Myerson, J. (2013). How Many Impulsivities? A Discounting Perspective. *Journal of the Experimental Analysis of Behavior*, *99*, 3–13. https://doi.org/10.1002/jeab.1.How

Green, L., Myerson, J., Lichtman, D., Rosen, S., & Fry, A. (1996). Temporal discounting in choice between delayed rewards: The role of age and income. *Psychology and Aging, 11*, 79–84. https://doi.org/10.1037/0882-7974.11.1.79

Green, L., Myerson, J., & McFadden, E. (1997). Rate of temporal discounting decreases with amount of reward. *Memory & Cognition, 25*, 715–723. https://doi.org/10.3758 /BF03211314

Green, L., Myerson, J., Oliveira, L., & Chang, S. E. (2013). Delay discounting of monetary rewards over a wide range of amounts. *Journal of the Experimental Analysis of Behavior,*

100, 269–281. https://doi.org/10.1002/JEAB.45

Green, L., Myerson, J., & Ostaszewski, P. (1999). Amount of Reward Has Opposite Effects on the Discounting of Delayed and Probabilistic Outcomes. *Journal of Experimental Psychology: Learning Memory and Cognition*, *25*, 418–427. https://doi.org/10.1037/0278-7393.25.2.418

Green, L., Myerson, J., & Vanderveldt, A. (2014). Delay and Probability Discounting. In F. K. McSweeney & E. S. Murphy (Eds.), *The Wiley Blackwell Handbook of Operant and Classical Conditioning* (pp. 307–337). Wiley Blackwell. https://doi.org/https://doi.org/10.1002/9781118468135.ch13

Gregorios-Pippas, L., Tobler, P. N., & Schultz, W. (2009). Short-term temporal discounting of reward value in human ventral striatum. *Journal of Neurophysiology*, *101*, 1507-1523. https://doi.org/10.1152/jn.90730.2008

Grilli, M. D., Wank, A. A., Bercel, J. J., & Ryan, L. (2018). Evidence for reduced autobiographical memory episodic specificity in cognitively normal middle-aged and older individuals at increased risk for Alzheimer's disease dementia. *Journal of the International Neuropsychological Society*, *24*, 1073–1083. https://doi.org/10.1017/ S1355617718000577

Grogan, J. P., Tsivos, D., Smith, L., Knight, B. E., Bogacz, R., Whone, A., & Coulthard, E. J. (2017). Effects of dopamine on reinforcement learning and consolidation in Parkinson's disease. *eLife*, *6*, e26801.

Gupta, R., Duff, M. C., Denburg, N. L., Cohen, N. J., Bechara, A., & Tranel, D. (2009). Declarative memory is critical for sustained advantageous complex decision-making. *Neuropsychologia*, *47*, 1686–1693. https://doi.org/10.1016/j.neuropsychologia.2009.02.007

Gutbrod, K., Kroužel, C., Hofer, H., Müri, R., Perrig, W., & Ptak, R. (2006). Decision-making in amnesia: Do advantageous decisions require conscious knowledge of previous behavioural choices? *Neuropsychologia*, *44*, 1315–1324. https://doi.org/10.1016/j.neuropsychologia.2006.01 .014

Haber, S., Knutson, B. (2010). The Reward Circuit: Linking Primate Anatomy and Human Imaging. *Neuropsychopharmacology* 35**,** 4–26. https://doi.org/10.1038/npp.2009.129

Hakimi, S., & Hare, T. A. (2015). Enhanced neural responses to imagined primary rewards predict reduced monetary temporal discounting. *Journal of Neuroscience*, *35*, 13103–13109. https://doi.org/10.1523/JNEUROSCI.1863-15.2015

Han, B. H., Moore, A. A., Sherman, S., Keyes, K. M., & Palamar, J. J. (2017). Demographic trends of binge alcohol use and alcohol use disorders among older adults in the United States, 2005–2014. *Drug and Alcohol Dependence*, *170*, 198–207. https://doi. org/10.1016/j.drugalcdep.2016.11.003

Hare, T. A., Hakimi, S., & Rangel, A. (2014). Activity in dlPFC and its effective connectivity to vmPFC are associated with temporal discounting. *Frontiers in Neuroscience*, *8*. https://doi.org/10.3389/fnins.2014.00050

Harrison, J., & McKay, R. (2012). Delay discounting rates are temporally stable in an Equivalent Present Value procedure using theoretical and Area Under the Curve analyses. *The Psychological Record*, *62*, 307–320. https://doi.org/10.1007/ BF03395804

Hebscher, M., & Gilboa, A. (2016). A boost of confidence: The role of the ventromedial prefrontal cortex in memory, decision-making, and schemas. *Neuropsychologia*, *90*, 46–58. https://doi.org/10.1016/j.neuropsychologia.2016.05.003

Henri-Bhargava, A., Simioni, A., & Fellows, L. K. (2012). Ventromedial frontal lobe damage

disrupts the accuracy, but not the speed, of value-based preference judgments. *Neuropsychologia*, *50*, 1536–1542. https://doi.org/10.1016/j.neuropsychologia.2012.03.006

Heo, W., Rabbani, A., & Grable, J. E. (2021). An Evaluation of the Effect of the COVID-19 Pandemic on the Risk Tolerance of Financial Decision Makers. *Finance Research Letters*, *41*, 101842. https://doi.org/10.1016/j.frl.2020.101842

Hiser, J., & Koenigs, M. (2018). The multifaceted role of the ventromedial prefrontal cortex in emotion, decision making, social cognition, and psychopathology. *Biological Psychiatry*, *83*, 638-647. https://doi.org/10.1016/j.biopsych.2017.10.030

Hochman, G., Yechiam, E., & Bechara, A. (2010). Recency gets larger as lesions move from anterior to posterior locations within the ventromedial prefrontal cortex. *Behavioural Brain Research*, *213*, 27–34. https://doi.org/10.1016/j .bbr.2010.04.023

Holdnack, H. A. (2001). *Wechsler Test of Adult Reading: WTAR*. San Antonio, TX: The Psychological Corporation.

Holt, D. D., Green, L., & Myerson, J. (2003). Is discounting impulsive? Evidence from temporal and probability discounting in gambling and non-gambling college students. *Behavioural Processes*, *64*, 355–367. https://doi.org/10.1016/S0376-6357(03)00141-4

Housden, C. R., O'Sullivan, S. S., Joyce, E. M., Lees, A. J., & Roiser, J. P. (2010). Intact reward learning but elevated delay discounting in Parkinson's disease patients with impulsive-compulsive spectrum behaviors. *Neuropsychopharmacology*, *35*, 2155–2164. https://doi.org/10.1038/npp.2010.84

Irish, M., Addis, D. R., Hodges, J. R., & Piguet, O. (2012). Exploring the content and quality of episodic future simulations in semantic dementia. *Neuropsychologia*, *50*, 3488–3495. https://doi.org/10.1016/j.neuropsychologia.2012.09.012

Irish, M., Eyre, N., Dermody, N., O'Callaghan, C., Hodges, J. R., Hornberger, M., & Piguet, O. (2016). Neural substrates of semantic prospection–Evidence from the dementias. *Frontiers in Behavioral Neuroscience*, *10*, 96. https://doi.org/10.3389/fnbeh.2016.00096

Irish, M., & Piguet, O. (2013). The pivotal role of semantic memory in remembering the past and imagining the future. *Behavioral Neuroscience*. https://doi.org/10.3389/fnbeh.2013.00027

Irish, M., & van Kesteren, M. T. R. (2018). New Perspectives on the Brain Lesion Approach – Implications for Theoretical Models of Human Memory. *Neuroscience*, *374*, 319–322. https://doi.org/10.1016/j.neuroscience.2017.10.049

Jeffreys, H. (1961). *Theory of probability* (3rd ed.). Oxford, UK: Oxford University Press.

Jimura, K., Chushak, M. S., & Braver, T. S. (2013). Impulsivity and self-control during intertemporal decision making linked to the neural dynamics of reward value representation. *Journal of Neuroscience*, *33*, 344-357. https://doi.org/10.1523/JNEUROSCI.0919-12.2013

Jimura, K., Chushak, M. S., Westbrook, A., & Braver, T. S. (2018). Intertemporal decision-making involves prefrontal control mechanisms associated with working memory. *Cerebral Cortex*, *28*, 1105-1116. https://doi.org/10.1093/cercor/bhx015

Jimura, K., Myerson, J., Hilgard, J., Keighley, J., Braver, T. S., & Green, L. (2011). Domain independence and stability in young and older adults' discounting of delayed rewards. *Behavioural Processes*, *87*, 253–259. https://doi.org/10.1016/j.beproc.2011.04.006

Jobson, D. D., Hase, Y., Clarkson, A. N., & Kalaria, R. N. (2021). The role of the medial prefrontal cortex in cognition, ageing and dementia. *Brain Communications*. https://doi.org/10.1093/braincomms/fcab125

Johnson, A., & Redish, A. D. (2007). Neural ensembles in CA3 transiently encode paths forward

of the animal at a decision point. *Journal of Neuroscience, 27*(45), 12176–12189. https://doi.org/10.1523/JNEUROSCI.3761-07.2007

Kable, J. W., & Glimcher, P. W. (2007). The neural correlates of subjective value during intertemporal choice. *Nature Neuroscience, 10*, 1625–1633. https://doi.org/10.1038/nn2007

Kable, J. W., & Glimcher, P. W. (2009). The Neurobiology of Decision: Consensus and Controversy. *Neuron, 63*, 733–745. https://doi.org/10.1016/j.neuron.2009.09.003

Kable, J. W., & Glimcher, P. W. (2010). An "As Soon As Possible" Effect in Human Intertemporal Decision Making: Behavioral Evidence and Neural Mechanisms. *Journal of Neurophysiology, 103*, 2513–2531. https://doi.org/10.1152/jn.00177.2009

Kagel, J. H., Green, L., & Caraco, T. (1986). When foragers discount the future: Constraint or adaptation? *Animal Behavior, 34*, 271–283. https://doi.org/10.1016/0003- 3472(86)90032-1

Kahneman, D., & Miller, D. T. (1986). Norm theory: Comparing reality to its alternatives. *Psychological Review, 93*, 136–153. https://doi.org/10.1037/0033-295X.93.2.136

Kahnt, T., Heinzle, J., Park, S. Q., & Haynes, J. D. (2011). Decoding different roles for vmPFC and dlPFC in multi-attribute decision making. *NeuroImage, 56*, 709–715. https://doi.org/10.1016/j.neuroimage.2010.05.058

Kan, I. P., Alexander, M. P., & Verfaellie, M. (2009). Contribution of prior semantic knowledge to new episodic learning in amnesia. *Journal of Cognitive Neuroscience, 21*(5), 938–944. https://doi.org/10.1162/jocn.2009.21066

Kan, I. P., Rosenbaum, R. S., & Verfaellie, M. (2020). Schema processing across the lifespan: From theory to applications. *Cognitive Neuropsychology, 37*, 1–7. https://doi.org/10.1080/02643294.2020.1736019

Kaplan, B. A., Reed, D. D., & Jarmolowicz, D. P. (2016). Effects of episodic future thinking on discounting: Personalized age-progressed pictures improve risky long-term health decisions. *Journal of Applied Behavior Analysis, 49,* 148–169. https://doi.org/10. 1002/jaba.277

Keven, N., Kurczek, J., Rosenbaum, R. S., & Craver, C. F. (2017). Narrative construction is intact in episodic amnesia. *Neuropsychologia, 110,* 104–112. https://doi.org/10 .1016/j.neuropsychologia.2017.07.028

Kim, B. K., & Zauberman, G. (2009). Perception of anticipatory time in temporal discounting. *Journal of Neuroscience, Psychology, and Economics, 2,* 91–101. https://doi. org/10.1037/a0017686

Kim, H., Schnall, S., & White, M. P. (2013). Similar psychological distance reduces temporal discounting. *Personality and Social Psychology Bulletin, 39,* 1005–1016. https://doi.org/10.1177/0146167213488214

Kimberg, D. Y., Coslett, H. B., & Schwartz, M. F. (2007). Power in voxel-based lesion-symptom mapping. *Journal of Cognitive Neuroscience, 19,* 1067–1080. https://doi.org /10.1162/jocn.2007.19.7.1067

Kirby, K. N. (2009). One-year temporal stability of delay-discount rates. *Psychonomic Bulletin and Review, 16,* 457–462. https://doi.org/10.3758/PBR.16.3.457

Klein, S. B. (2013). The complex act of projecting oneself into the future. *Wiley Interdisciplinary Reviews: Cognitive Science, 4,* 63–79. https://doi.org/10.1002/wcs.1210

Kluwe-Schiavon, B., Viola, T. W., Bandinelli, L. P., Castro, S. C. C., Kristensen, C. H., Costa, J. C. da, & Grassi-Oliveira, R. (2021). A behavioral economic risk aversion experiment in the context of the COVID-19 pandemic. *PLoS ONE, 16.* https://doi.org/10.1371/journal.pone.0245261

Knowlton, B. J., Mangels, J. A., & Squire, L. R. (1996). A neostriatal habit learning system in humans. *Science*, *273*, 1399-1402. https://doi.org/10.1126/science.273.5280.1399

Kurczek, J., Wechsler, E., Ahuja, S., Jensen, U., Cohen, N. J., Tranel, D., & Duff, M. (2015). Differential contributions of hippocampus and medial prefrontal cortex to self-projection and self-referential processing. *Neuropsychologia*, *73*, 116–126. https://doi.org/10.1016/j.neuropsychologia.2015.05.002

Kurth-Nelson, Z., Bickel, W., & Redish, A. D. (2012). A theoretical account of cognitive effects in delay discounting. *European Journal of Neuroscience*, *35*, 1052–1064. https://doi.org/10.1111/J.1460-9568.2012.08058.X

Kurtz-David, V., Persitz, D., Webb, R., & Levy, D. J. (2019). The neural computation of inconsistent choice behavior. *Nature Communications*, *10*, 1–14. https://doi.org/10.1038/s41467-019-09343-2

Kwan, D., Craver, C. F., Green, L., Myerson, J., Boyer, P., & Rosenbaum, R. S. (2012). Future decision-making without episodic mental time travel. *Hippocampus*, *22*, 1215–1219. https://doi.org/10.1002/hipo.20981

Kwan, D., Craver, C. F., Green, L., Myerson, J., Gao, F., Black, S. E., & Rosenbaum, R. S. (2015). Cueing the personal future to reduce discounting in intertemporal choice: Is episodic prospection necessary? *Hippocampus*, *25*, 432–443. https://doi.org/10.1002/hipo.22431

Kwan, D., Craver, C. F., Green, L., Myerson, J., & Rosenbaum, R. S. (2013). Dissociations in Future Thinking Following Hippocampal Damage : Evidence From Discounting and Time Perspective in Episodic Amnesia. *Journal of Experimental Psychology: General*, *142*, 1355–1369. https://doi.org/10.1037/a0034001

Kwan, D., Kurczek, J., & Rosenbaum, R. S. (2016). Specific, personally meaningful cues can benefit episodic prospection in medial temporal lobe amnesia. *British Journal of Clinical Psychology*, *55*, 137–153. https://doi.org/10.1111/bjc .12095

Lapp, L. K., & Spaniol, J. (2017). Impact of age-relevant goals on future thinking in younger and older adults. *Memory*, *25*, 1246–1259. https://doi.org/10.1080/09658211.2017.1284240

Lee, M. D., & Wagenmakers, E. -J. (2013). Bayesian cognitive modeling: A practical course. Cambridge University Press

Leland, J. W., & Grafman, J. (2005). Experimental tests of the somatic marker hypothesis. *Games and Economic Behavior*, *52*, 386–409. https://doi.org/10.1016/j.geb.2004.09.001

Lempert, K. M., & Phelps, E. A. (2016). The malleability of intertemporal choice. *Trends in Cognitive Sciences*, *20*, 64–74. https://doi.org/10.1016/j.tics.2015.09.005

Levine, B., Svoboda, E., Hay, J. F., Winocur, G., & Moscovitch, M. (2002). Aging and autobiographical memory: Dissociating episodic from semantic retrieval. *Psychology and Aging*, *17*, 677–689. https://doi.org/10.1037/0882-7974.17.4.677

Levy, D. J., & Glimcher, P. W. (2012). The root of all value: A neural common currency for choice. In *Current Opinion in Neurobiology* (Vol. 22, Issue 6, pp. 1027–1038). https://doi.org/10.1016/j.conb.2012.06.001

Lieberman, M. D., Straccia, M. A., Meyer, M. L., Du, M., & Tan, K. M. (2019). Social, self, (situational), and affective processes in medial prefrontal cortex (MPFC): Causal, multivariate, and reverse inference evidence. In *Neuroscience and Biobehavioral Reviews*, *99*, 311-328. https://doi.org/10.1016/j.neubiorev.2018.12.021

Lin, H., & Epstein, L. H. (2014). Living in the moment: Effects of time perspective and emotional valence of episodic thinking on delay discounting. *Behavioral Neuroscience, 128*, 12–19. https://doi.org/10.1037/a0035705

Lin, W. J., Horner, A. J., Bisby, J. A., & Burgess, N. (2015). Medial prefrontal cortex: adding value to imagined scenarios. *Journal of Cognitive Neuroscience, 27*, 1957-1967. https://doi.org/10.1162/jocn_a_00836

Liu, L., Feng, T., Chen, J., & Li, H. (2013). The value of emotion: How does episodic prospection modulate delay discounting? *PLoS One, 8,* e81717. https://doi.org/10.1371/journal.pone.0081717

Liu, L. L., Chen, X. J., Cui, J. F., Wang, J., Zhang, Y. B., Neumann, D. L., ... Chan, R. C. (2016). Age differences in delay discounting in Chinese adults. *Personality and Individual Differences, 90,* 205–209. https://doi.org/10.1016/j.paid.2015.11.006

Loewenstein, G. F., Weber, E. U., Hsee, C. K., & Welch, N. (2001). Risk as feelings. *Psychological Bulletin, 127,* 267-286. https://doi.org/10.1037/0033-2909.127.2.267

Locey, M. L., Jones, B. A., & Rachlin, H. (2011). Real and hypothetical rewards. *Judgment and Decision Making, 6,* 552–564.

Löckenhoff, C. E. (2011). Age, time, and decision making: From processing speed to global time horizons. *Annals of the New York Academy of Sciences, 1235,* 44–56. https://doi.org/10.1111/j.1749-6632.2011.06209.x

Lockenhoff, C. E., O'Donoghue, T., & Dunning, D. (2011). Age differences in temporal discounting: The role of dispositional affect and anticipated emotions. *Psychology and Aging, 26,* 274. https://doi.org/10.1037/a0023280

Logue, A. W. (1988). Research on self-control: An integrating framework. *Behavioral and Brain*

Sciences, 11, 665–679. https://doi.org/10.1017/S0140525X00053978

Loomes, G., & Sugden, R. (1982). Regret theory: An alternative theory of rational choice under uncertainty. *Economic Journal, 92*, 805–824. https://doi.org/10.2307/2232669

Ludwig, V. U., Nüsser, C., Goschke, T., Wittfoth-Schardt, D., Wiers, C. E., Erk, S., Schott, B. H., & Walter, H. (2015). Delay discounting without decision-making: medial prefrontal cortex and amygdala activations reflect immediacy processing and correlate with impulsivity and anxious-depressive traits. *Frontiers in Behavioral Neuroscience, 9*, 280. https://doi.org/10.3389/fnbeh.2015.00280

Luhmann, C. C. (2009). Temporal decision-making: Insights from cognitive neuroscience. *Frontiers in Behavioral Neuroscience*, 3. https://doi.org/10.3389/neuro.08.039.2009

Luhmann, C. C., Chun, M. M., Yi, D. J., Lee, D., & Wang, X. J. (2008). Neural dissociation of delay and uncertainty in intertemporal choice. *Journal of Neuroscience*, *28*, 14459–14466. https://doi.org/10.1523/ JNEUROSCI.5058 -08.

MacKillop, J., Weafer, J., Gray, J. C., Oshri, A., Palmer, A., & de Wit, H. (2016). The latent structure of impulsivity: Impulsive choice, impulsive action. *and impulsive personality traits. Psychopharmacology, 233*, 3361–3370. https://doi.org/10.1007/s00213-016- 4372-0

Madden, G. J., Begotka, A. M., Raiff, B. R., & Kastern, L. L. (2003). Delay discounting of real and hypothetical rewards. *Experimental and Clinical Psychopharmacology, 11*, 139–145. https://doi.org/10.1037/1064-1297.11.2.139

Madden, G. J., & Bickel, W. K. (2010). *Impulsivity: The behavioral and neurological science of discounting*. Washington: American Psychological Association. https://doi.org/10.1037/12069-000

Malesza, M., & Ostaszewski, P. (2020). Assessing individual differences in discounting:

Construction and initial validation of the Discounting Inventory. *Current Psychology*, *39*, 207–219. https://doi.org/10.1007/s12144-017-9754-x

Mata, R., Josef, A. K., Samanez-Larkin, G. R., & Hertwig, R. (2011). Age differences in risky choice: A meta-analysis. *Annals of the New York Academy of Sciences*, *1235*, 18–29. https://doi.org/10.1111/j.1749-6632.2011.06200.x

Mazur, J. E., & Biondi, D. R. (2011). Effects of time between trials on rats' and pigeons' choices with probabilistic delayed reinforcers. *Journal of the Experimental Analysis of Behavior*, *95*, 41–56. https://doi.org/10.1901/jeab.2011.95-41

McClure, S. M., Laibson, D. I., Loewenstein, G., & Cohen, J. D. (2004). Separate neural systems value immediate and delayed monetary rewards. *Science*, *306*, 503–507. https://doi.org/10.1126/science.1100907

McCormick, C., Barry, D. N., Jafarian, A., Barnes, G. R., & Maguire, E. A. (2020). VmPFC Drives Hippocampal Processing during Autobiographical Memory Recall Regardless of Remoteness. *Cerebral Cortex*, *30*, 5972–5987. https://doi.org/10.1093/cercor/bhaa172

McCormick, C., Ciaramelli, E., De Luca, F., & Maguire, E. A. (2018). Comparing and Contrasting the Cognitive Effects of Hippocampal and Ventromedial Prefrontal Cortex Damage: A Review of Human Lesion Studies. *Neuroscience*, *374*, 295–318. https://doi.org/10.1016/j.neuroscience.2017.07.066

McCormick C, Rosenthal CR, Miller TD, Maguire EA (2017) Deciding what is possible and impossible following hippocampal damage in humans. Hippocampus 27, 303–314. https://doi.org/10.1002/hipo.22694

McCoy, B., Jahfari, S., Engels, G., Knapen, T., & Theeuwes, J. (2019). Dopaminergic medication reduces striatal sensitivity to negative outcomes in Parkinson's

disease. *Brain, 142*, 3605-3620. https://doi.org/10.1093/brain/awz276

McKerchar, T. L., & Renda, C. R. (2012). Delay and probability discounting in humans: An overview. *Psychological Record, 62*, 817–834. https://doi.org/10.1007/BF03395837

Mejía-Cruz, D., Green, L., Myerson, J., Morales-Chainé, S., & Nieto, J. (2016). Delay and probability discounting by drug-dependent cocaine and marijuana users. *Psychopharmacology, 233*, 2705–2714. https://doi.org/10.1007/s00213-016-4316-8

Mellis, A. M., Snider, S. E., Deshpande, H. U., LaConte, S. M., & Bickel, W. K. (2019). Practicing prospection promotes patience: Repeated episodic future thinking cumulatively reduces delay discounting. *Drug and Alcohol Dependence, 204*, 107507. https://doi.org/10.1016/j.drugalcdep.2019.06.010

Milenkova, M., Mohammadi, B., Kollewe, K., Schrader, C., Fellbrich, A., Wittfoth, M., Dengler, R., & Münte, T. F. (2011). Intertemporal choice in Parkinson's disease. *Movement Disorders, 26*, 2004–2010. https://doi.org/10.1002/mds.23756

Mobini, S., Body, S., Ho, M. Y., Bradshaw, C., Szabadi, E., Deakin, J., et al. (2002). Effects of lesions of the orbitofrontal cortex on sensitivity to delayed and probabilistic reinforcement. *Psychopharmacology, 160*, 290–298. https://doi.org/10.1007/s00213-001-0983-0, PMID: 11889498

Mohr, P. N. C., Li, S. C., & Heekeren, H. R. (2010). Neuroeconomics and aging: Neuromodulation of economic decision making in old age. *Neuroscience and Biobehavioral Reviews, 34*, 678–688. https://doi.org/10.1016/j.neubiorev.2009.05.010

Mok, J. N., Green, L., Myerson, J., Kwan, D., Kurczek, J., Ciaramelli, E., ... & Rosenbaum, S. R. (2021). Does Ventromedial Prefrontal Cortex Damage Really Increase Impulsiveness? Delay and Probability Discounting in Patients with Focal Lesions. *Journal of Cognitive*

Neuroscience, 1-19.

Mok, J. N. Y., Kwan, D., Green, L., Myerson, J., Craver, C. F., & Rosenbaum, R. S. (2020). Is it time? Episodic imagining and the discounting of delayed and probabilistic rewards in young and older adults. *Cognition, 199*, 104222. https://doi .org/10.1016/j.cognition.2020.104222

Montague, P. R., & Berns, G. S. (2002). Neural economics and the biological substrates of valuation. *Neuron, 36*, 265–284. https://doi.org/10.1016/S0896-6273(02)00974-1

Moss, S. A., & Wilson, S. G. (2018). Why are older people often so responsible and considerate even when their future seems limited? A systematic review. *The International Journal of Aging and Human Development, 86*, 82–108. https://doi.org/10.1177/ 0091415017689883

Muhammed, K., Manohar, S., Ben Yehuda, M., Chong, T. T. J., Tofaris, G., Lennox, G., ... & Husain, M. (2016). Reward sensitivity deficits modulated by dopamine are associated with apathy in Parkinson's disease. *Brain*, *139*, 2706-2721. https://doi.org/10.1093/brain/aww188

Myers-Schulz, B., & Koenigs, M. (2012). Functional anatomy of ventromedial prefrontal cortex: implications for mood and anxiety disorders. *Molecular Psychiatry*, *17*, 132-141.

Myerson, J., Baumann, A. A., & Green, L. (2017). Individual Differences in Delay Discounting: Differences are Quantitative with Gains, but Qualitative with Losses. *Journal of Behavioral Decision Making*, *30*, 359–372. https://doi.org/10.1002/bdm.1947

Myerson, J., Green, L., Hanson, J., Holt, D. D., & Estle, S. J. (2003). Discounting delayed and probabilistic rewards: Processes and traits. *Journal of Economic Psychology*, *24*, 619–635. https://doi.org/10.1016/S0167-4870(03)00005-9

Myerson, J., Green, L., & Morris, J. (2011). Modeling the effect of reward amount on probability discounting. *Journal of the Experimental Analysis of Behavior*, *95*, 175–187. https://doi.org/10.1901/JEAB.2011.95-175

Myerson, J, Green, L., & Warusawitharana, M. (2001). Area under the curve as a measure of discounting. *Journal of the Experimental Analysis of Behavior, 76*, 235–243. https://doi.org/10.1901/jeab.2001.76-235

Nadel, L., & Moscovitch, M. (1997). Memory consolidation, retrograde amnesia and the hippocampal complex. *Current Opinion in Neurobiology, 7*, 217–227. https://doi.org/10.1016/S0959-4388(97)80010-4

Nan, X., & Qin, Y. (2018). How thinking about the future affects our decisions in the present: Effects of time orientation and episodic future thinking on responses to health warning messages. *Human Communication Research, 45,* 148–168. https://doi. org/10.1093/hcr/hqy017

Noonan, M., Mars, R., Sallet, J., Dunbar, R. I. M., & Fellows, L. K. (2018). The structural and functional brain networks that support human social networks. *Behavioural Brain Research, 355*, 12-23. https://doi.org/10.1016/j.bbr.2018.02.019

Nyberg, L., Lövdén, M., Riklund, K., Lindenberger, U., & Bäckman, L. (2012). Memory aging and brain maintenance. *Trends in Cognitive Sciences, 16,* 292-305. https://doi.org/10.1016/j.tics.2012.04.005

O'Donnell, S., Oluyomi Daniel, T., & Epstein, L. H. (2017). Does goal relevant episodic future thinking amplify the effect on delay discounting? *Consciousness and Cognition, 51,* 10–16. https://doi.org/10.1016/j.concog.2017.02.014

O'Donnell, S., Daniel, T. O., Koroschetz, J., Kilanowski, C., Otminski, A., Bickel, W. K., & Epstein, L. H. (2019). Do process simulations during episodic future thinking enhance the reduction of delay discounting for middle income participants and those living in poverty? *Journal of Behavioral Decision Making, 32*, 231–240. https://doi.org/10. 1002/bdm.2108

Odum, A. L. (2011). Delay discounting: Trait variable? *Behavioural Processes*, *87*, 1–9. https://doi.org/10.1016/j.beproc.2011.02.007

Odum, A. L., Becker, R. J., Haynes, J. M., Galizio, A., Frye, C. C. J., Downey, H., Friedel, J. E., & Perez, D. M. (2020). Delay discounting of different outcomes: Review and theory. *Journal of the Experimental Analysis of Behavior*, *113*, 657–679. https://doi.org/10.1002/JEAB.589

Ohmura, Y., Takahashi, T., Kitamura, N., & Wehr, P. (2006). Three-month stability of delay and probability discounting measures. *Experimental and Clinical Psychopharmacology*, *14*(3), 318–328. https://doi.org/10.1037/1064-1297.14.3.318

Paglieri, F., Addessi, E., De Petrillo, F., Laviola, G., Mirolli, M., Parisi, D., Petrosino, G., Ventricelli, M., Zoratto, F., & Adriani, W. (2014). Nonhuman gamblers: Lessons from rodents, primates, and robots. *Frontiers in Behavioral Neuroscience*, *8*. https://doi.org/10.3389/fnbeh.2014.00033

Palombo, D. J., Keane, M. M., & Verfaellie, M. (2015a). How does the hippocampus shape decisions? *Neurobiology of Learning and Memory*. *125*, 93-97. https://doi.org/10.1016/j.nlm.2015.08.005

Palombo, D. J., Keane, M. M., & Verfaellie, M. (2015b). The medial temporal lobes are critical for reward-based decision making under conditions that promote episodic future thinking. *Hippocampus*, *25*, 345–353. https://doi.org/10.1002/hipo.22376

Palombo, D. J., Keane, M. M., & Verfaellie, M. (2016). Using future thinking to reduce temporal discounting: Under what circumstances are the medial temporal lobes critical? *Neuropsychologia*, *89*, 437–444. https://doi.org/10.1016/j.neuropsychologia. 2016.07.002

Patton, J. H., Stanford, M. S., & Barratt, E. S. (1995). Factor structure of the Barratt

impulsiveness scale. *Journal of Clinical Psychology, 51,* 768–774. https://doi.org/10.1002/1097-4679(199511)51:6<768::AID-JCLP2270510607>3.0.CO;2-1

Peters, J. (2011). The role of the medial orbitofrontal cortex in intertemporal choice: Prospection or valuation? *Journal of Neuroscience, 31,* 5889–5890. https://doi.org/10.1523/JNEUROSCI.0268-11.2011

Peters, J., & Büchel, C. (2009). Overlapping and Distinct Neural Systems Code for Subjective Value during Intertemporal and Risky Decision Making. *Journal of Neuroscience, 29,* 15727–15734. https://doi.org/10.1523/JNEUROSCI.3489-09.2009

Peters, J., & Büchel, C. (2010). Episodic Future Thinking Reduces Reward Delay Discounting through an Enhancement of Prefrontal-Mediotemporal Interactions. *Neuron, 66,* 138–148. https://doi.org/10.1016/j.neuron.2010.03.026

Peters, J., & Büchel, C. (2011). The neural mechanisms of inter-temporal decision-making: understanding variability. *Trends in Cognitive Sciences, 15*. 227-239. https://doi.org/10.1016/j.tics.2011.03.002

Peters, J., & D'Esposito, M. (2016). Effects of Medial Orbitofrontal Cortex Lesions on Self-Control in Intertemporal Choice. *Current Biology, 26,* 2625–2628. https://doi.org/10.1016/J.CUB.2016.07.035

Peters, J., & D'Esposito, M. (2020). The drift diffusion model as the choice rule in inter-temporal and risky choice: A case study in medial orbitofrontal cortex lesion patients and controls. *PLOS Computational Biology, 16,* e1007615. https://doi.org/10.1371/JOURNAL.PCBI.1007615

Pujara, M. S., Wolf, R. C., Baskaya, M. K., & Koenigs, M. (2015). Ventromedial prefrontal cortex damage alters relative risk tolerance for prospective gains and losses.

Neuropsychologia, *79*, 70–75. https://doi.org/10.1016/j.neuropsychologia.2015.10.026

Quintana, D. S., & Williams, D. R. (2018). Bayesian alternatives for common null-hypothesis significance tests in psychiatry: A non-technical guide using JASP. *BMC Psychiatry, 18*, 178. https://doi.org/10.1186/s12888-018-1761-4

Race, E., Keane, M. M., & Verfaellie, M. (2011). Medial temporal lobe damage causes deficits in episodic memory and episodic future thinking not attributable to deficits in narrative construction. *Journal of Neuroscience*, *31*, 10262–10269. https://doi.org/10.1523/JNEUROSCI.1145-11.2011

Rachlin, H. (2006). Notes on Discounting. *Journal of the Experimental Analysis of Behavior*, *85*, 425–435. https://doi.org/10.1901/JEAB.2006.85-05

Rachlin, H., Raineri, A., & Cross, D. (1991). Subjective Probability and Delay. *Journal of the Experimental Analysis of Behavior*, *55*, 233–244. https://doi.org/10.1901/jeab.1991.55-233

Rangel, A., Camerer, C., & Montague, P. R. (2008). A framework for studying the neurobiology of value-based decision making. *Nature Reviews Neuroscience*, *9*, 545–556. https://doi.org/10.1038/nrn2357

Rangel, A., & Clithero, J. A. (2012). Value normalization in decision making: theory and evidence. *Current Opinion in Neurobiology*, *22*, 970–981. https://doi.org/10.1016/j.conb.2012.07.011

Raz, N. (2004). The aging brain: Structural changes and their implications for cognitive aging. In R. Dixon, L. Backman, & L.-G. Nilsson (Eds.). *New frontiers in cognitive aging* (pp. 115–133). New York: Oxford University Press. https://doi.org/10.1093/acprof:oso/9780198525691.003.0006

Read, D., & Read, N. L. (2004). Time discounting over the lifespan. *Organizational Behavior*

and Human Decision Processes, 94, 22–32. https://doi.org/10.1016/j.obhdp. 2004.01.002

Reber, J., Feinstein, J. S., O'Doherty, J. P., Liljeholm, M., Adolphs, R., & Tranel, D. (2017). Selective impairment of goal-directed decision-making following lesions to the human ventromedial prefrontal cortex. *Brain, 140*, 1743–1756. https://doi.org/10.1093/brain/awx105

Reimers, S., Maylor, E. A., Stewart, N., & Chater, N. (2009). Associations between a oneshot delay discounting measure and age, income, education and real-world impulsive behavior. *Personality and Individual Differences*, *47*, 973–978

Robin, J., Rivest, J., Rosenbaum, R. S., & Moscovitch, M. (2019). Remote spatial and autobiographical memory in cases of episodic amnesia and topographical disorientation. *Cortex*, *119*, 237–257. https://doi.org/10.1016/j.cortex.2019.04 .013

Rorden, C., & Brett, M. (2000). Stereotaxic display of brain lesions. *Behavioural Neurology*, *12*, 191–200. https:// doi.org/10.1155/2000/421719

Rosenbaum, R S, Kwan, D., Floden, D., Levine, B., Stuss, D. T., & Craver, C. F. (2016). No evidence of risk-taking or impulsive behaviour in a person with episodic amnesia: Implications for the role of the hippocampus in future-regarding decision-making. *Quarterly Journal of Experimental Psychology (2006), 69*, 1606–1618. https://doi.org/10.1080/17470218.2015.1090461

Rosenbaum, R Shayna, Gilboa, A., Levine, B., Winocur, G., & Moscovitch, M. (2009). Amnesia as an impairment of detail generation and binding: Evidence from personal, fictional, and semantic narratives in K.C. *Neuropsychologia*. https://doi.org/10.1016/j.neuropsychologia.2008.11.028

Rosenbaum, R Shayna, Moscovitch, M., Foster, J. K., Schnyer, D. M., Gao, F., Kovacevic, N.,

Verfaellie, M., Black, S. E., & Levine, B. (2008). Patterns of autobiographical memory loss in medial-temporal lobe amnesic patients. *Journal of Cognitive Neuroscience*, *20*, 1490–1506. https://doi.org/10.1162/jocn.2008.20105

Rotter, J. (1954). Social learning and clinical psychology. Englewood Cliffs NJ: Prentice Hall. https://doi.org/10.1037/10788-000

Rubin, D. C., & Umanath, S. (2015). Event memory: A theory of memory for laboratory, autobiographical, and fictional events. *Psychological Review*, *122*, 1–23. https://doi.org/10.1037/a0037907

Roy, M., Shohamy, D., & Wager, T. D. (2012). Ventromedial prefrontal-subcortical systems and the generation of affective meaning. *Trends in Cognitive Sciences*, *16*, 147-156. https://doi.org/10.1016/j.tics.2012.01.005

Rubin, R. D., Watson, P. D., Duff, M. C., & Cohen, N. J. (2014). The role of the hippocampus in flexible cognition and social behavior. *Frontiers in Human Neuroscience*, *8*, https://doi.org/10.3389/fnhum.2014.00742

Rung, J. M., & Madden, G. J. (2018). Experimental reductions of delay discounting and impulsive choice: A systematic review and meta-analysis. *Journal of Experimental Psychology: General*, *147*, 1349–1381. https://doi.org/10.1037/xge0000462

Rung, J. M., & Madden, G. J. (2019). Demand Characteristics in Episodic Future Thinking II:The Role of Cues and Cue Content in Changing Delay Discounting. *Experimental and Clinical Psychopharmacology*, *27*, 482–495. https://doi.org/10.1037/pha0000260

Rutt, J. L., & Lockenhoff, C. E. (2016). From past to future: Temporal self-continuity across the life span. *Psychology and Aging, 31*, 631–639. https://doi.org/10.1037/ pag0000090

Sasse, L. K., Peters, J., & Brassen, S. (2017). Cognitive control modulates effects of episodic simulation on delay discounting in aging. *Frontiers in Aging Neuroscience, 9*, 58. https://doi.org/10.3389/fnagi.2017.00058

Sasse, L. K., Peters, J., Buchel, C., & Brassen, S. (2015). Effects of prospective thinking on intertemporal choice: The role of familiarity. *Human Brain Mapping, 36*, 4210–4221. https://doi.org/10.1002/hbm.22912

Schacter, D. L., & Addis, D. R. (2007). The cognitive neuroscience of constructive memory: Remembering the past and imagining the future. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *362*(1481), 773–786. https://doi.org/10.1098/rstb.2007.2087

Schacter, D. L., & Addis, D. R. (2009). On the Nature of Medial Temporal Lobe Contributions to the Constructive Simulation of Future Events. *Philosophical Transactions of the Royal Society B*, *364*, 1245–1253. https://doi.org/10.1093/acprof:oso/9780195395518.003.0024

Schacter, D. L., & Addis, D. R. (2020). Memory and imagination: Perspectives on constructive episodic simulation. *The Cambridge Handbook of Imagination, A. Abraham, Ed.(Cambridge University Press, Cambridge, England, 2020)*, 111-131. https://doi.org/10.26226/morressier.60dd99435d86378f03b413f9

Schacter, D. L., Addis, D. R., Hassabis, D., Martin, V. C., Spreng, R. N., & Szpunar, K. K. (2012). The Future of Memory: Remembering, Imagining, and the Brain. *Neuron*, *76*, 677–694. https://doi.org/10.1016/j.neuron.2012.11.001

Schacter, D. L., Benoit, R. G., De Brigard, F., & Szpunar, K. K. (2015). Episodic future thinking and episodic counterfactual thinking: Intersections between memory and decisions. *Neurobiology of Learning and Memory, 117*, 14–21. https://doi.org/10.1016/j.nlm.2013.12.008

Schacter, D. L., Benoit, R. G., & Szpunar, K. K. (2017). Episodic future thinking: mechanisms and functions. *Current Opinion in Behavioral Sciences*, *17*, 41–50. https://doi.org/10.1016/j.cobeha.2017.06.002

Schacter, D. L., Gaesser, B., & Addis, D. R. (2013). Remembering the past and imagining the future in the elderly. *Gerontology*, *59*, 143-151. https://doi.org/10.1159/000342198

Schacter DL, Devitt AL, & Addis DR (2018). Episodic future thinking and cognitive aging *In Oxford Encyclopedia of Psychology and Aging*. Oxford University Press. https://doi.org/10.1093/acrefore/9780190236557.013.380

Schaie, K. W., & Willis, S. L. (Eds.). (2016). *Handbook of the psychology of aging*(8th ed.). San Diego, CA: Elsevier Academic Press. https://doi.org/10.1016/C2009-0-01966-7

Schmidt, L., Tusche, A., Manoharan, N., Hutcherson, C., Hare, T., & Plassmann, H. (2018). Neuroanatomy of the vmPFC and dlPFC predicts individual differences in cognitive regulation during dietary self-control across regulation strategies. *Journal of Neuroscience*, *38*, 5799-5806. https://doi.org/10.1523/JNEUROSCI.3402-17.2018

Schubert, T., Eloo, R., Scharfen, J., & Morina, N. (2020). How imagining personal future scenarios influences affect: Systematic review and meta-analysis. *Clinical Psychology Review*, *75*. https://doi.org/10.1016/j.cpr.2019.101811

Schultz, W. (2007). Behavioral dopamine signals. *Trends in Neurosciences*, *30*, 203-210. https://doi.org/10.1016/j.tins.2007.03.007

Seaman, K. L., Brooks, N., Karrer, T. M., Castrellon, J. J., Perkins, S. F., Dang, L. C., Hsu, M., Zald, D. H., & Samanez-Larkin, G. R. (2018). Subjective value representations during effort, probability and time discounting across adulthood. *Social Cognitive and Affective Neuroscience*, *13*, 449–459. https://doi.org/10.1093/scan/nsy021

Seaman, K. L., Gorlick, M. A., Vekaria, K. M., Hsu, M., Zald, D. H., & Samanez-Larkin, G. R. (2016). Adult age differences in decision making across domains: Increased discounting of social and health-related rewards. *Psychology and Aging*, *31*, 737. https://doi.org/10.1037/PAG0000131

Sellitto, M., Ciaramelli, E., & di Pellegrino, G. (2010). Myopic Discounting of Future Rewards after Medial Orbitofrontal Damage in Humans. *Journal of Neuroscience*, *30*, 16429–16436. https://doi.org/10.1523/JNEUROSCI.2516-10.2010

Sellitto, M., Ciaramelli, E., & Di Pellegrino, G. (2011). The neurobiology of intertemporal choice: Insight from imaging and lesion studies. *Reviews in the Neurosciences*, *22*, 565–574. https://doi.org/10.1515/RNS.2011.046

Sharp, M. E., Foerde, K., Daw, N. D., & Shohamy, D. (2016). Dopamine selectively remediates 'model-based'reward learning: a computational approach. *Brain*, *139*, 355-364. https://doi.org/10.1093/brain/awv347

Sharp, M. E., Duncan, K., Foerde, K., & Shohamy, D. (2020). Dopamine is associated with prioritization of reward-associated memories in Parkinson's disease. *Brain*, *143*, 2519-2531. https://doi.org/10.1093/brain/awaa182

Shohamy, D., & Wagner, A. D. (2008). Integrating Memories in the Human Brain: Hippocampal-Midbrain Encoding of Overlapping Events. *Neuron*, *60*, 378–389. https://doi.org/10.1016/J.NEURON.2008.09.023

Siegert, R. J., Taylor, K. D., Weatherall, M., & Abernethy, D. A. (2006). Is implicit sequence learning impaired in Parkinson's disease? A meta-analysis. *Neuropsychology*, *20*, 490. https://doi.org/10.1037/0894-4105.20.4.490

Snider, S. E., LaConte, S. M., & Bickel, W. K. (2016). Episodic future thinking: Expansion of

the temporal window in individuals with alcohol dependence. *Alcoholism: Clinical and Experimental Research, 40,* 1558-1566. https://doi.org/10.1111/acer.13112

Snowden, J. S., Bathgate, D., Varma, A., Blackshaw, A., Gibbons, Z. C., & Neary, D. (2001). Distinct behavioural profiles in frontotemporal dementia and semantic dementia. *Journal of Neurology Neurosurgery and Psychiatry, 70,* 323–332. https://doi.org/10.1136/jnnp.70.3.323

Spalding, K. N., Jones, S. H., Duff, M. C., Tranel, D., & Warren, D. E. (2015). Investigating the neural correlates of schemas: Ventromedial prefrontal cortex is necessary for normal schematic influence on memory. *Journal of Neuroscience, 35,* 15746–15751. https://doi.org/10.1523/JNEUROSCI.2767-15.2015

Spaniol, J., Di Muro, F., & Ciaramelli, E. (2019). Differential impact of ventromedial prefrontal cortex damage on "hot" and "cold" decisions under risk. *Cognitive, Affective, & Behavioral Neuroscience, 19,* 477–489. https://doi.org /10.3758/s13415-018-00680-1

Sparrow, E. P., & Spaniol, J. (2016). Age-related changes in decision making. *Current Behavioral Neuroscience Reports, 3,* 285–292. https://doi.org/10.1007/s40473-016- 0091-4

Sparrow, E. P., & Spaniol, J. (2018). Aging and altruism in intertemporal choice. *Psychology and Aging, 33,* 315–324. https://doi.org/10.1037/pag0000223

Spreen, O., & Strauss, E. (1998). *A compendium of neuropsychological tests: Administration, norms, and commentary* (2nd ed.). New York: Oxford University Press.

St. Jacques, P. L., & Levine, B. (2007). Ageing and autobiographical memory for emotional and neutral events. *Memory, 15,* 129–144. https://doi.org/10.1080/ 09658210601119762

St. Onge, J. R., & Floresco, S. B. (2010). Prefrontal cortical contribution to risk-based decision making. *Cerebral Cortex, 20,* 1816–1828. https://doi.org/10.1093/cercor/bhp250

Stanford, M. S., Mathias, C. W., Dougherty, D. M., Lake, S. L., Anderson, N. E., & Patton, J. H. (2009). Fifty years of the Barratt Impulsiveness Scale: An update and review. *Personality and Individual Differences*, *47*(5), 385–395. https://doi.org/10.1016/j.paid.2009.04.008

Stawarczyk, D., Cassol, H., & D'Argembeau, A. (2013). Phenomenology of future-oriented mind-wandering episodes. *Frontiers in Psychology*, *4*(JUL). https://doi.org/10.3389/fpsyg.2013.00425

Stawarczyk, D., & D'Argembeau, A. (2015). Neural correlates of personal goal processing during episodic future thinking and mind-wandering: An ALE meta-analysis. *Human Brain Mapping*, *36*, 2928–2947. https://doi.org/10.1002/HBM.22818

Stein, J. S., Tegge, A. N., Turner, J. K., & Bickel, W. K. (2018). Episodic future thinking reduces delay discounting and cigarette demand: an investigation of the good-subject effect. *Journal of Behavioral Medicine*, *41*, 269-276. https://doi.org/10.1007/s10865-017-9908-1

Steinglass, J. E., Lempert, K. M., Choo, T. H., Kimeldorf, M. B., Wall, M., Walsh, B. T., Fyer, A. J., Schneier, F. R., & Simpson, H. B. (2017). Temporal discounting across three psychiatric disorders: anorexia nervosa, obsessive compulsive disorder, and social anxiety disorder. *Depression and Anxiety*, *34*, 463-470. https://doi.org/10.1002/da.22586

Stendardi, D., Biscotto, F., Bertossi, E., & Ciaramelli, E. (2021). Present and future self in memory: the role of vmPFC in the self-reference effect. *Social Cognitive and Affective Neuroscience, 2021*, 1–9. https://doi.org/10.1093/scan/nsab071

Stern, E. R., Welsh, R. C., Fitzgerald, K. D., Gehring, W. J., Lister, J. J., Himle, J. A., Abelson, J. L., & Taylor, S. F. (2011). Hyperactive error responses and altered connectivity in ventromedial and frontoinsular cortices in obsessive-compulsive disorder. *Biological*

Psychiatry, *69*, 583-591. https://doi.org/10.1016/j.biopsych.2010.09.048

Strikwerda-Brown, C., Hodges, J., Piguet, O., & Irish, M. (2020). Examining the episodic-semantic interplay during future thinking-A reanalysis of external details. *PsyArXiv*. https://doi.org/10.31234/osf.io/9yszk

Stuss, D. T. (2006). Frontal lobes and attention: Processes and networks, fractionation and integration. *Journal of the International Neuropsychological Society*, *12*, 261–271. https://doi.org/10.1017/S1355617706060358

Stuss, D. T. (2017). Frontal lobes. In J. S. Kreutzer, J. DeLuca, & B. Caplan (Eds.), *Encyclopedia of clinical neuropsychology* (2nd ed.). Cham, Switzerland: Springer. https://doi.org /10.1007/978-3-319-56782-2_318-2

Stuss, D. T., & Levine, B. (2002). Adult clinical neuropsychology: Lessons from studies of the frontal lobes. *Annual Review of Psychology*, *53*, 401–433. https://doi.org/10.1146 /annurev.psych.53.100901.135220

Stuss, D. T., Rosenbaum, R. S., Malcolm, S., Christiana, W., & Keenan, J.P. (2005). The frontal lobes and self-awareness. In T. E. Feinberg & J. P. Keenan (Eds.), *The lost self: Pathologies of the brain and identity* (pp. 50–64). New York: Oxford University Press. https://doi.org/10.1093/acprof:oso /9780195173413.003.0005

Szpunar, K. K., Spreng, R. N., & Schacter, D. L. (2014). A taxonomy of prospection: Introducing an organizational framework for future-oriented cognition. *Proceedings of the National Academy of Sciences*, *111*, 18414–18421. https://doi.org/10.1073/pnas.1417144111

Szpunar, K. K., Watson, J. M., & McDermott, K. B. (2007). Neural substrates of envisioning the future. *Proceedings of the National Academy of Sciences*, *104*, 642–647. https://doi.org/10.1073/pnas.0610082104

Taylor, S. E., & Schneider, S. K. (1989). Coping and the simulation of events. *Social Cognition, 7*, 174–194. https://doi.org/10.1521/soco.1989.7.2.174

Thorstad, R., & Wolff, P. (2018). A big data analysis of the relationship between future thinking and decision-making. *Proceedings of the National Academy of Sciences*, *115*, E1740–E1748. https://doi.org/10.1073/pnas.1706589115

, Y., & Liberman, N. (2010). Construal-level theory of psychological distance. *Psychological Review, 117*, 440–463. https://doi.org/10.1037/a0018963

Tulving, E. (2002). Episodic memory: From mind to brain. *Annual Review of Psychology, 53*, 1–25. https://doi.org/10.1146/annurev.psych.53.100901.135114

Vaidya, A. R., & Fellows, L. K. (2015). Ventromedial frontal cortex is critical for guiding attention to reward-predictive visual features in humans. *Journal of Neuroscience*, *35*, 12813–12823. https://doi.org/10.1523/JNEUROSCI.1607-15.2015

Vaidya, A. R., Sefranek, M., & Fellows, L. K. (2018). Ventromedial Frontal Lobe Damage Alters how Specific Attributes are Weighed in Subjective Valuation. *Cerebral Cortex*, *28*, 3857–3867. https://doi.org/10.1093/CERCOR/BHX246

van der Meer, M. A. A., Johnson, A., Schmitzer-Torbert, N. C., & Redish, A. D. (2010). Triple Dissociation of Information Processing in Dorsal Striatum, Ventral Striatum, and Hippocampus on a Learned Spatial Decision Task. *Neuron*, *67*, 25–32. https://doi.org/10.1016/J.NEURON.2010.06.023

Vanderveldt, A., Green, L., & Rachlin, H. (2017). Discounting by Probabilistic Waiting. *Journal of Behavioral Decision Making*, *30*(1), 39–53. https://doi.org/10.1002/bdm.1917

Verfaellie, M., Wank, A. A., Reid, A. G., Race, E., & Keane, M. M. (2019). Self-related processing and future thinking: Distinct contributions of ventromedial prefrontal cortex and

the medial temporal lobes. *Cortex, 115*. https://doi.org/10.1016/j.cortex.2019.01.028

Voon, V., & Fox, S. H. (2007). Medication-related impulse control and repetitive behaviors in Parkinson disease. *Archives of Neurology, 64*, 1089–1096. https://doi.org/10.1001/archneur.64.8.1089

Wagner, D. D., Haxby, J. V., & Heatherton, T. F. (2012). The representation of self and person knowledge in the medial prefrontal cortex. *Wiley Interdisciplinary Reviews: Cognitive Science, 3,* 451-470. https://doi.org/10.1002/wcs.1183

Wang, T., Mellis, A. M., Lau, N., & Bickel, W. (2019). Integrating Episodic Future Thinking into Virtual Reality to Mitigate Substance Use Disorders: A Theoretical Framework. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 63*, 2282-2286. https://doi.org/10.1177/1071181319631026

Wang, T., Yue, T., & Huang, X. T. (2016). Episodic and semantic memory contribute to familiar and novel episodic future thinking. *Frontiers in Psychology, 7,* 1746. https://doi.org/10.3389/fpsyg.2016.01746

Weber, B. J., & Huettel, S. A. (2008). The neural substrates of probabilistic and intertemporal decision making. *Brain Research, 1234*, 104–115. https://doi.org/10.1016/j.brainres.2008.07.105

Wheeler, M. A., Stuss, D. T., & Tulving, E. (1997). Toward a theory of episodic memory: The frontal lobes and autonoetic consciousness. *Psychological Bulletin, 121*, 331–354. https://doi.org/10.1037//0033-2909.121.3.331

Whiteside, S. P., Port, J. D., & Abramowitz, J. S. (2004). A meta–analysis of functional neuroimaging in obsessive–compulsive disorder. *Psychiatry Research: Neuroimaging, 132,* 69-79. https://doi.org/10.1016/j.pscychresns.2004.07.001

Wiehler, A., Bromberg, U., & Peters, J. (2015). The role of prospection in steep temporal reward discounting in gambling addiction. *Frontiers in Psychiatry, 6*, 112. https://doi.org/10.3389/fpsyt.2015.00112

Wittmann, M., & Lehnhoff, S. (2005). Age effects in perception of time. *Psychological Reports, 97*, 921–935. https://doi.org/10.2466/PR0.97.7.921-935

Wu, W. H., Cheng, W., & Chiou, W. B. (2017). Episodic future thinking about the ideal self induces lower discounting, leading to a decreased tendency toward cheating. *Frontiers in Psychology*, *8*, 287. https://doi.org/10.3389/fpsyg.2017.00287

Yeh, Y.-H., Myerson, J., Strube, M. J., & Green, L. (2020). Choice patterns reveal qualitative individual differences among discounting of delayed gains, delayed losses, and probabilistic losses. *Journal of the Experimental Analysis of Behavior*, *113*, 609–625. https://doi.org/10.1002/JEAB.597

Yi, R., Mitchell, S. H., & Bickel, W. K. (2010). Delay discounting and substance abuse-dependence. In *Impulsivity: The Behavioral and Neurological Science of Discounting.* (pp. 191–211). https://doi.org/10.1037/12069-007

Yu, L. Q., Kan, I. P., & Kable, J. W. (2020). Beyond a rod through the skull: A systematic review of lesion studies of the human ventromedial frontal lobe. *Cognitive Neuropsychology*, *37*, 97–141. https://doi.org/10.1080/02643294.2019.1690981

Zeithamova, D., Dominick, A. L., & Preston, A. R. (2012). Hippocampal and ventral medial prefrontal activation during retrieval-mediated learning supports novel inference. *Neuron*, *75*, 168–179. https://doi.org/10.1016/j.neuron.2012.05.010

Appendix A

Psychometric Conversion Table

Standard Score	Percentile	T-Score	Z-Score	Scaled Score	Label
45	0.02	13	-3.54	0	Impaired
46	0.03	14	-3.43	0	
47	0.04	14	-3.35	0	
48	0.05	15	-3.29	0	
49	0.06	16	-3.24	0	
50	0.07	17	-3.19	0	
51	0.08	17	-3.16	0	
52	0.09	18	-3.12	0	
53	0.1	18	-3.09	0	
54	0.2	19	-2.88	1	
55	0.3	20	-2.75	1	
56	0.4	21	-2.65	1	
57	0.5	21	-2.58	1	
58	0.6	22	-2.51	2	
59	0.7	22	-2.46	2	
60	0.8	23	-2.41	2	
61	0.9	24	-2.37	2	
62	1	25	-2.33	3	
63	1	25	-2.33	3	
64	1	26	-2.33	3	
65	1	26	-2.33	3	
66	1	27	-2.33	3	
67	1	28	-2.33	3	
68	2	29	-2.05	4	
69	2	29	-2.05	4	Impaired
70	2	30	-2.05	4	Borderline
71	3	30	-1.88	4	
72	3	31	-1.88	5	
73	4	32	-1.75	5	
74	4	33	-1.75	5	
75	5	33	-1.64	5	
76	5	34	-1.64	5	
77	6	34	-1.55	5	
78	7	35	-1.48	6	
79	8	36	-1.41	6	
80	9	37	-1.34	6	Low Average
81	10	37	-1.28	6	
82	12	38	-1.17	6	
83	13	39	-1.13	6	
84	14	39	-1.08	7	
85	16	40	-0.99	7	
86	18	41	-0.92	7	
87	19	41	-0.88	7	
88	21	42	-0.81	8	
89	23	42	-0.74	8	
90	25	43	-0.67	8	Average
91	27	44	-0.61	8	
92	30	45	-0.52	8	
93	32	45	-0.47	8	
94	34	46	-0.41	9	
95	37	46	-0.33	9	
96	39	47	-0.28	9	
97	42	48	-0.20	9	
98	45	48	-0.13	9	
99	47	49	-0.08	10	
100	50	50	0.00	10	
101	53	51	0.08	10	Average
102	55	51	0.13	10	
103	58	52	0.20	11	
104	61	53	0.28	11	
105	63	53	0.33	11	
106	66	54	0.41	11	
107	68	55	0.47	11	
108	70	55	0.52	12	
109	73	56	0.61	12	
110	75	57	0.67	12	High Average
111	77	57	0.74	12	
112	79	58	0.81	12	
113	81	59	0.88	12	
114	82	59	0.92	13	
115	84	60	0.99	13	
116	86	61	1.08	13	
117	87	61	1.13	13	
118	88	62	1.17	14	
119	90	62	1.28		
120	91	63	1.34	14	Superior
121	92	64	1.41	14	
122	93	65	1.48	14	
123	94	65	1.55	14	
124	95	66	1.64	15	
125	95	66	1.64	15	
126	96	67	1.75	15	
127	96	68	1.75	15	
128	97	69	1.88	16	
129	97	69	1.88	16	
130	98	70	2.05	16	Very Superior
131	98	70	2.05	16	
132	98	71	2.05	16	
133	99	72	2.33	17	
134	99	73	2.33	17	
135	99	73	2.33	17	
136	99	74	2.33	17	
137	99	74	2.33	17	
138	99	75	2.33	17	
139	99.1	76	2.37	18	
140	99.2	77	2.41	18	
141	99.3	77	2.46	18	
142	99.4	78	2.51	18	
143	99.5	78	2.58	18	
144	99.6	79	2.65	19	
145	99.7	80	2.75	19	
146	99.8	81	2.88	19	
147	99.9	81	3.09	19	
148	99.91	82	3.12	20	
149	99.92	82	3.16	20	
150	99.93	83	3.19	20	
151	99.94	84	3.24	20	
152	99.95	85	3.29	20	
153	99.96	85	3.35	20	
154	99.97	86	3.43	20	
155	99.98	86	3.54	20	