IS IT TIME? EXAMINING THE EFFECTS OF EPISODIC IMAGINING ON REWARD DISCOUNTING

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Abstract

"Mental time-travel" affords us the ability to simulate hypothetical episodes that shape our decisions about the future, as documented on tests of intertemporal choice where personal cueing greatly reduces future reward discounting. Despite this robust finding, it is unclear whether this modulatory effect is due to the induction of episodic imagining. If so, the effect should not generalize to forms of discounting that are without a temporal component. To test this, young healthy adults completed a temporal discounting task and a non-temporal, probability discounting task with and without personal cues. Contrary to the results from delay discounting, no differences in probability discounting were observed between the cued and baseline versions. The results suggest a specific interaction between episodic imagining and future-oriented judgements that is not seen in all forms of decision-making, extending our understanding of the limits within which episodic cueing guides personal, financial choices.

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Is It Time? Examining the Effects of Episodic Imagining on Reward Discounting

Inherent in our ability to remember the past and imagine the future is the ability to vividly construct a mental projection of ourselves outside of the present moment. By engaging in these episodic thoughts, we can simulate how we may think and feel at other times in other places, as well as anticipate the thoughts and feelings of other people. These personal, imagined experiences might serve as a source of our self-identity, which may help us to regulate emotional states, and allow for more precise, goal-directed behaviours to imagine and plan for the future (Boyer, 2008; Kahneman & Miller, 1986; Taylor & Schneider, 1989). Understanding the critical contributions of episodic thought to other cognitive capacities will, in turn, provide insight into the behavioural and neural mechanisms underlying the recollection and imagining of personally meaningful experiences (Craver, Kwan, Steindam, & Rosenbaum, 2014; Schacter, Benoit, & Szpunar, 2017).

Findings from neuroimaging and lesion studies have demonstrated that episodic memory may indeed be involved in our ability to simulate hypothetical episodes about ourselves across time, allowing us to plan and make decisions about the future (Addis, Wong, & Schacter, 2007; Schacter & Addis, 2009; Szpunar, 2010). This is evident in studies where vivid episodic imagining has been found to increase regard for future rewards. One fMRI study looked at intertemporal choice, which is the consideration of the consequential decisions that individuals make across time (Berns, Laibson, & Loewenstein, 2007). In this study, typical young adults were asked to select between fixed, immediate rewards and larger, delayed rewards. In the trials where the reward option was presented alongside a personal episodic cue, recruitment of future thinking reduced the discounting of later rewards and increased the consideration of the future outcomes (Peters & Büchel, 2010). These findings were replicated by Benoit, Gilbert, and

Burgess (2011) in a similar paradigm, showing again that valuing of future rewards over immediate payoffs increases when individuals are thinking about specific future episodes. Notably, both fMRI studies found increased activity within, and coordination among, the hippocampus and ventromedial prefrontal cortex, two brain regions known to underlie episodic imagining, when participants were asked to consider episodic future event cues. Coupling of these regions during episodic imagining indicated a coordinated effort by episodic memory and goal-directed systems to process future payoffs and choices (Bar, 2010; Buckner & Carroll, 2007; Peters & Büchel, 2010; Schacter & Addis, 2009).

The influence of episodic imagining on other forms of future decision-making is reinforced by findings in hippocampal amnesic individuals. Despite impaired episodic memory and future imagining, these individuals are nonetheless capable of some forms of future thinking, such as making future-oriented decisions like those in the studies described above (Kwan et al., 2012; Kwan, Craver, Green, Myerson, & Rosenbaum, 2013). However, delay discounting in most amnesic individuals are impervious to the effects of episodic cueing seen in typical adults (Kwan et al., 2015; Palombo, Keane, & Verfaellie, 2015). One possibility that requires clarification is whether it is the temporal, episodic nature of the cues that mediates hypothetical future choices rather than increased attention to the reward values or some other nonepisodic factor. If so, a question that follows is whether the same effects will be seen in other forms of decision-making that do not have a temporal component, such as those that require risk-taking choices of uncertainty. The current thesis examines the nature of episodic, personally meaningful cues, and their role in modulating decision-making by using a probabilistic choice-based task that does not require time-based judgments.

Episodic memory and future imagining: An intimate relationship

The hippocampus and surrounding regions within the medial temporal lobe (MTL) have long been considered essential for the formation of consciously accessible, declarative memories, and for the temporary retention and retrieval of those memories in the service of long-term consolidation (Scoville & Milner, 1957; Squire, 1992; Tulving, 2002). These declarative memories comprise the semantic knowledge we have acquired about the world and ourselves, as well as the recollection of episodic details from past, personal experiences reflected via spatiotemporal processes (Tulving, 1985). Insight into the cognitive mechanisms of the brain has been derived from human lesion studies, and is supported by neuroimaging findings. More recent evidence indicates that the hippocampus and the MTL are needed to maintain the details of episodic memories, no matter how long ago they were formed. Strong evidence comes from studies of amnesic individuals who exhibit extensive impairments in recollection of episodic details following extensive MTL damage (e.g., Steinvorth, Levine, & Corkin, 2005) and even following more selective lesions to the hippocampus (Moscovitch et al., 2005; Rosenbaum et al., 2008) and to its major output, the fornix (Gilboa et al., 2006).

But what about imagining the future? As the evidence for the role of the hippocampus in episodic retrieval and mental re-enactment of past events accumulates, more recent research has examined whether the hippocampus serves a role in episodic simulation processes that also considers thinking about the future. Early on, Tulving (1985) recognized that episodic memory may contribute to a bidirectional concept of “mental time travel” (Suddendorf & Corballis, 1997). This builds on the idea of autonoetic consciousness (Tulving, 1983), whereby we examine our own thoughts and behaviours by mentally transferring ourselves from the present to the remote past or distant future. Others have suggested that *memory for the future*, “like memories of past events, can be remembered, often in great detail” (Ingvar, 1985, p. 128). Thus, conceiving future events before they occur through information gathered from the past may offer a more multifaceted purpose for the hippocampus that deviates from the traditional view that its role is limited to memory. Indeed, past experiences may be useful in helping us to shape the future by allowing us to anticipate, regulate, and "pre-experience" plausible scenarios (Atance & O'Neill, 2001).

Episodic simulation: Connecting the past, present, and future

Convincing evidence that our ability to remember the past is linked to our thoughts of the future is revealed by cognitive and neurological similarities between remembering past events and imagining future outcomes. This is exemplified in findings across multiple studies showing that both temporally distant past and future events are (re)constructed at a more abstract level and have qualitatively less episodic and sensory details compared to temporally closer events (e.g., Addis et al., 2008; D'Argembeau & Van der Linden, 2004; Szpunar & McDermott, 2008; also see *Temporal Construal Theory*, Liebermann & Trope, 2003). More direct findings of a common neural substrate are reported in studies of amnesic patients with extensive hippocampal damage. These individuals express severe difficulties in their recollection of detailed, personal episodic memories and imagining of future experiences despite retention of remote semantic memories formed long ago (Gilboa et al., 2005; Rosenbaum et al., 2005, 2009). Patient K.C., who suffered a head injury that led to extensive bilateral hippocampal damage, is one of the best documented individuals with impaired episodic thought relating to the personal past and future. More recent testing of K.C., as well as other amnesic individuals, has confirmed that impairments in detailed recollection of past events and imagining of vivid, personal events may co-exist because of damage to the hippocampus (Klein, Loftus, & Khilstrom, 2002; Kwan et al., 2010; Race et al., 2011; Rosenbaum et al., 2009).

A unified capacity for mental time travel in humans is further supported by findings from neuroimaging research that episodic remembering and future imagining are governed by an overlapping network of brain regions. To explain these commonalities, Buckner and Carroll (2007) proposed that this network of brain regions underpins our overall ability to engage in self-projection beyond the present. That is, our ability to mentally travel through time serves a greater, more flexible purpose, allowing us to disengage from the immediate environment to consider alternate perspectives of time, space, and even other people's mental states (see Saxe & Kanwisher, 2003, on *theory of mind*). Active engagement of the medial and lateral temporal lobes along with a common network of other brain regions that includes the medial prefrontal, posterior parietal, and posterior cingulate/retrosplenial cortices is seen during tasks related to episodic recollection and future thinking (Addis et al., 2007; Benoit & Schacter, 2015; Hassabis, Kumaran, Vann, & Maguire, 2007; Okuda et al., 2003; Szpunar, Watson, & McDermott, 2007). What remains to be solved is the root of this common neural network. Could this network be involved in the common representation of time, space, and the self; or could brain regions like the hippocampus be involved in the construction of episodic details, irrespective of time?

If it is true that the involvement of the hippocampus in future imagining is consistent with an ability to mentally travel through time to (re)experience an event, this would suggest that the hippocampus contributes to a temporal function in remembering the past and thinking about the future. In the rodent literature, suggestion that the hippocampus is concerned with time is based on studies of hippocampal *time cells*. When rats performed tasks that require remembering a sequence of events, such as seeking out certain odours in a maze, CA1 principal cells in the hippocampus were shown to fire unique temporal coding patterns for specific memories that were repeated, controlled by the temporal cues and critical intervals during the elapsed time period (Manns, Howard, & Eichenbaum, 2007; see Eichenbaum, 2013, for a review). In humans, this has been likened to imagining future scenarios, though the time scales of rodent and human activities differ considerably. One possibility is that constructing imagined future scenarios enhances encoding of new information, whereas recollection of past experiences or imagining scenarios without a temporal component does not require hippocampal input (Klein et al., 2010). Neuroimaging has also shown that distinct regions associated with the network described by Schacter et al. (2012), Buckner and Carroll (2007), and others may be more associated with personal future imagining compared to past or present scenarios (Andrews-Hanna, Reidler, Sepulcre, Poulin, & Buckner, 2010). The challenge, however, is the difficulty in separating temporal factors from constructive properties. With respect to the latter, most studies of episodic future imagining do not differentiate these two components, with future imagining often requiring greater reliance on narrative construction (see Hassabis et al., 2007, and Kwan et al., 2012, for similar arguments). Such limitations raise questions as to whether previous studies delineating our abilities to remember the past and imagine the future have thoroughly separated these two commonly converging factors.

An alternative possibility is that the two abilities are similar in their reliance on constructing and binding of temporal, spatial, and other event-related details into coherent narratives. Evidence for this has been found in studies of narrative and scene construction in the absence of imagining a specific time (Hassabis et al., 2007; Herdman, Calarco, Moscovitch, Hirshhorn, & Rosenbaum, 2015; Rosenbaum et al., 2009). Systematic studies involving hippocampal amnesic patients have shown that deficits to the reconstruction of past information and construction of new concepts may involve similar mechanisms that require constructing and binding details into narratives; failure to do so leads to impoverished responses lacking in rich imagery and elements that are independent of time. For example, when asked to imagine fictional event information and to recount details of well-known semantic narratives, the well-studied amnesic person K.C. could only provide a gist or general framework that lacked vivid detail (Rosenbaum et al., 2009; see also Verfaellie, Bousquet, & Keane, 2014). Description of scenes that are not specific to a past or future time period were also fragmented and incoherent, a deficit that appears to parallel impaired construction of future events (Hassabis et al., 2007).

Several theories have attempted to account for these findings. *Multiple Trace Theory* posits that the hippocampus plays a role in binding disparate elements together, both spatially and temporally (Moscovitch et al., 2005; Nadel & Moscovitch, 1997). In this view, the hippocampus creates memory traces of reconstructed episodic details and elements, allowing older memories to become less vulnerable to disruptions. An extension of this viewpoint is the *Trace Transformation Theory* (Winocur & Moscovitch, 2011), which surmises that hippocampus-dependent, episodic memories occur in conjunction with schematic, gist-like memories and may explain the findings described previously in studies regarding the extent to which amnesic patients can produce and construct rich, detailed narratives. Both theories point to the hippocampally dependent process of reconsolidation. This ability to reactivate memories, due to existing memory traces, also suggests that the hippocampus is continuously engaged during episodic retrieval (but see Squire, 1992, for a countering view). This suggests that consolidation of information, as described by Multiple Trace Theory, is a dynamic process in which memories of past experiences can be susceptible to interference, but can also be extrapolated, leading to organization and construction of novel, future-oriented thoughts. Thus, retrieval of past events and imagining future events may rely on the hippocampus in a similar fashion – integrating episodic details into a coherent manner (Addis, Moscovitch, Crawley, & McAndrews, 2004).

An alternative idea, the *Scene Construction Theory*, posits that the hippocampus is responsible for facilitating scene construction irrespective of time. Important to this theory is that episodic memories and imagined future experiences emerge from the construction of spatial context and details, and relates to episodic mnemonic processes to a lesser extent. Our abilities to (re)construct coherent narratives that allows us to mental time travel are, therefore, reliant on our abilities to create rich spatial tapestries in our minds (Hassabis & Maguire, 2007; Maguire & Mullally, 2013). Failure to imagine such scenes has been observed in patients with hippocampal damage who also possess a loss of episodic memory (Hassabis et al., 2007). Further evidence supporting this theory comes from a recent fMRI study showing hippocampal engagement in the boundary extension phenomenon, whereby people extend the borders of recently viewed scenes beyond what was physically present (Chadwick, Mullally, & Maguire, 2013). Thus, in accordance with this theory, the hippocampus appears to influence our perspective of the world through spatially described experiences, again suggesting a role that does not prominently serve a temporally oriented function (for exceptions in a hippocampal amnesic case see Hassabis et al., 2007, and Squire et al., 2010).

This proposition of a more nuanced constructive function of the hippocampus is in line with the *Constructive Episodic Simulation Hypothesis* proposed by Schacter and Addis (2007). It describes a functional cognitive system that can repurpose the meaningful elements of past experiences to create equally meaningful future portrayals, and can serve an adaptive utility in preventing neural overload. This constructive engagement of the hippocampus may reflect retrieval of episodic details that are essential for both remembering the past and imagining future events. The emphasis placed by the Constructive Episodic Simulation Hypothesis on the flexible retrieval and reconstruction of information from previous experiences into future episodes may offer a theoretical framework for the role of the hippocampus in episodic simulation in human cognition that can be applied to other instances requiring future thinking. The Constructive Episodic Simulation Hypothesis invites the possibility that the functional property of the hippocampus, which appears to govern episodic projections across time, could also be useful for making adaptive responses and appropriate behaviours when considering the future. This latter proposition has been investigated in recent research on intertemporal choice.

The role of episodic simulation in intertemporal choice

An area of research that may hold a clue to understanding the relationship between episodic memory and future imagining can be found within the cognitive domain of decision-making. Boyer (2008) described an important contribution of imagining and constructing future experiences in decision-making, and suggested that it may offer a crucial driving force motivating goal-directed behaviour. Imagining future experiences may steer people towards suitable delayed outcomes in lieu of near-sighted choices, bringing long-term outcomes closer in subjective time to the present. The hippocampus 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).

The adaptive value for human decision-making has been considered in the study of intertemporal choice given the frequently assumed reliance that this behavioural mechanism has on episodic simulation. The study of intertemporal choice, which considers the ways individuals make comparative choices across time, describes a fundamental aspect of impulsive decision-making in which people tend to forego, or discount, a larger future reward and choose a smaller, more immediate reward based on the increasing temporal disparity (length of time) required to receive the delayed reward (Green & Myerson, 2004). Here, impulsiveness is defined as a failure to account for the consequences of actions and failure to suppress an immediate reaction to a stimulus (Eysenck, 1993, cited in Richards, Zhang, Mitchell, & de Wit, 1999; Floden, Alexander, Kubu, Katz, & Stuss, 2008). In the context of delay discounting, steeper discounting curves have been associated with greater impulsivity in decision-making (see Green & Myerson, 2004, for a discussion). Mounting evidence has shown, however, that when prompted with personal cues of vivid events or actions while making these choices, greater regard for future-oriented decisions and insight emerges, which leads to a reduction in impulsivity and need for immediate gratification. Younger adults have shown valuation of future rewards to a greater degree over immediate rewards when thinking about specific future episodes (Benoit et al., 2011; Peters & Büchel, 2010). In fact, preferences for the delayed and larger financial outcome is seen even when the cues offered to the participants are drastically modified. A review of the literature by Bulley, Henry, and Suddendorf (2016) found that reduction of future discounting occurred in a number of varying conditions, including participants imagining actual consumption of the delayed rewards (e.g., Benoit et al, 2011; Palombo, Keane, & Verfaellie, 2015, 2016); the reward being received contiguously with the unfolding of personally meaningful events (e.g., Kwan et al., 2015; Palombo et al., 2015a; Peters & Büchel, 2010); general future events about themselves (e.g., Cheng et al., 2012); or content for a simulated episode that had not been previously experienced or encountered (e.g., Sasse, Peters, Büchel, & Brassen, 2015). Attenuation of discounting also occurs even when the vividness or recency of the cued event is manipulated (e.g., Daniel et al., 2015; Lin & Epstein, 2014; Liu et al., 2013). Complementary to these findings, increased coupling of activity within the MTL and ventromedial prefrontal cortices, areas of the brain implicated in both episodic simulation and decision-making, predicted the magnitude of attenuation seen in the participants' choices (Peters & Büchel, 2010).

While this modulatory effect is quite robust in healthy individuals, a surprising discrepancy exists when considering populations that may have a reduced episodic imagining capacity. Paradoxically, hippocampal amnesic patients demonstrate intact performance when completing delay discounting tasks that require some form of future thinking without construction of episodic events. That is, amnesic individuals show similar rates of delay discounting as controls, and even show the same magnitude pattern for discounting curves, where discounting is less steep for larger future rewards (Kwan et al., 2012; 2013). Interestingly, the modulatory effect of episodic cueing is not as apparent in most of these cases. Unlike controls, most of the amnesic patients' discounting curves were relatively unchanged when engaging in future imagining (Kwan et al., 2015; Palombo et al., 2015a), suggesting that this form of decision-making is sensitive to episodic future imagining. However, it is unclear if it is the temporal, episodic nature of the cues that is responsible for increased consideration of future rewards or if it is some other factor, such as the specificity or personal meaningfulness of the cue that increases its saliency and draws greater attention to, and/or processing of, the future reward.

One way to address this issue, which has been attempted previously (Palombo et al., 2016), is to incorporate nontemporal cues, such as semantic cues, into the intertemporal choice paradigm. Palombo et al. (2016) found that discounting curves of healthy adults differed from amnesic patients when thinking of the items that they would purchase with the reward received. Healthy adults were more inclined to select the future over the immediate reward after engaging in semantic future thinking, but amnesic patients showed reduced temporal discounting only when the items presented in the study to be purchased were explicitly tagged to the time period in which the item would be bought. Without such scaffolding, only healthy participants actively chose the delayed rewards. This presents the possibility that the cues provided to participants led to deeper, more vivid processing of the objects independent of time. Another way is to apply personal cues to a nontemporal discounting paradigm. If personal cues induce episodic future imagining, then a task that does not have a temporal component, such as probability discounting, should not be affected by the provision of such cues. If, however, personal cues induce specificity or personal meaningfulness, then delay and probability discounting should be similarly modulated by cueing.

Probability discounting paradigms have been frequently used in the field of behavioural economics as a means of measuring risk-taking and impulsivity. In these tasks, individuals choose between receiving a smaller, guaranteed reward and a larger reward with varying degrees of uncertainty of its receipt. More importantly, probability discounting paradigms have been described to share common properties with delay discounting, with both having been correlated with personality measures of impulsivity to some degree (Richards et al., 1999). Other evidence, however, suggests that delay and probability discounting behave differently, which argues against the notion that the two operate as a single process. For example, although both probability and delay discounting functions share the same mathematical form (Green & Myerson, 2004), variation in reward amount shows opposite effects on the rates of delay and probability discounting (Green, Myerson, & Ostaszewski, 1999). Performance differences also occur depending on the type of reward (Charlton & Fantino, 2008; Estle, Green, Myerson, & Holt, 2007) and whether the reward is a gain or loss (Estle, Green, Myerson, & Holt, 2006).

Despite certain differences, a recent study by Kaplan, Reed, and Jarmolowicz (2016) examining the effects of personal cueing found that probabilistic, risky choices could be mediated in a similar fashion as delayed rewards. Using a modified episodic future thinking procedure, participants were exposed to age-progressed images of themselves and responded to questions about lifestyle changes that would positively or negatively affect one's health to a certain probability in the future. These pictorial cues reduced discounting compared to a baseline condition. Although this study is limited by applying personal cueing to a probability discounting task that was confounded by a temporal element, it is the first published finding that supports the role of personal cueing in possibly other forms of decision-making. Thus, the probability discounting task may serve as substitute for the delay discounting tasks that are traditionally used in studies investigating episodic simulation and future thinking.

Taken together, findings from intertemporal choice suggest that the relationship between episodic memory and future imagining, and the role for the hippocampus in the two, rests on the constructive aspect of these processes independent of the temporal components. However, cues used to elicit episodic imagining are also likely to engage concrete, specific thinking rather than mental time travel per se. If this is the case, discounting tasks that do not have a temporal component may be similarly influenced by personal cues. As an evaluative follow-up to Kaplan et al. (2016) and to the previous findings indicating evidence for both episodic and semantic cueing responses in healthy adults (Kwan et al., 2015; Palombo et al., 2016), the current study clarified whether personal cues were sufficient to modulate choices in an atemporal probability discounting task. Younger adult participants were administered delay discounting and probability discounting paradigms, both with and without personal cues. If temporality of the cues is necessary for the effect to take place, then a nontemporal decision-making task like probability discounting should not show the same modulation seen in delay discounting tasks. If it is the case that the modulatory effect of personal cues in delay discounting is not due to the induction of mental time travel, then similar effects should be seen when participants are cued to think about specific personal experiences while making probabilistic choices that do not have an obvious temporal component.

Method

Participants

Undergraduate-level students from York University were recruited to participate in a two-session study. During the initial session, participants were screened to have normal or corrected-to-normal vision and no reported history of neurological or psychiatric illnesses. The participants were also screened for variables associated with deviant discounting behaviour, including smoking, significant alcohol and illicit drug use, and problems with gambling (Madden & Bickel, 2010). One participant withdrew after the initial session. Data were collected from the remaining 32 participants (13 females; M = 20.24 years, SD = 2.36), and will be discussed in this thesis. All participants gave informed written consent in accordance with the Human Research Ethics Committees at York University and Baycrest Hospital. Participants received course credit for their participation.

Materials and Procedure

Participants completed both standard and cued versions of a probability discounting task. To evaluate and compare the role of personal cues in decision-making, the participants also completed standard and cued versions of an intertemporal choice (delay discounting) task previously used by Kwan et al. (2015) (also see Kwan et al., 2012; 2013). Across both discounting paradigms, the standard version of each task was completed prior to the cued versions of the task to provide a baseline for measuring the effect of personal cueing and to ensure that any benefits from cueing did not influence the baseline discounting rates. An additional concern that was considered was potential carry over responses from one type of discounting task to the other. This was deemed unlikely given previous findings that repeated measuring of similar decision-making tasks do not change rate of responses (Kwan et al., 2012; 2013). Furthermore, the cues that were generated for both the probability and delay discounting tasks were distinct and did not overlap. Nevertheless, the probability and delay discounting tasks were completed on separate days to ensure that participants were cognitively invested in each task. The two sets of tasks were counterbalanced across all participants, with close to half of the participants assigned to complete the probability discounting tasks during the first session and the delay discounting tasks during the second session, and the other half assigned to complete the cued and noncued delay discounting tasks first and the cued and noncued probability discounting tasks on the second day. The cued condition, for both discounting tasks, were completed immediately following the standard condition. For both sets of discounting tasks, the position of the immediate/guaranteed amount on the screen was randomized such that the immediate/guaranteed amount was equally likely to be presented to the left or to the right of the delayed/probabilistic value. All tasks employed hypothetical rewards, which is a common practice in discounting research due to feasibility, particularly when delay to receipt of reward is lengthy (e.g., longer than 1 year).[1]

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[1] All the rewards in this study were hypothetical, which raises the question of whether decisions would be made differently if the incentives were real. Numerous studies have directly investigated this question by comparing hypothetical versus real rewards in financial decision making and other reward outcomes, in both probability and delay discounting (Bickel, Pitcock, Yi, & Angtuaco, 2009; Dixon, Mui Ker Lik, Green, & Myerson, 2013; Hinvest & Anderson, 2000; Johnson & Bickel, 2002; Locey, Jones, & Rachlin, 2011; Madden, Begotka, Raiff, & Kastern, 2003). That different reward types are discounted similarly despite differences in tangibility suggests that the hypothetical rewards used in the current study are generalizable to real monetary decisions.

Probability Discounting Tasks

Standard probability discounting. Probability discounting is an established measure of risk-taking that has been utilized across disciplines and has been used in recent years in healthy young and older adults (Holt, Green, & Myerson, 2003; Lindbergh, Puente, Gray, MacKillop, & Miller, 2014; Peters & Büchel, 2009; Seaman et al., 2016), and in amnesic patients (Kwan et al., 2013). Over a series of trials, participants were presented with hypothetical monetary values on a computer screen and asked to make choices between a smaller, "for sure" reward and a larger, probabilistic reward. For each of two probabilistic amounts ($250 and $2000), participants completed a block where they 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 Kwan et al. (2013), an iterative, amount-adjusting procedure (i.e., the decrease or increase of the guaranteed reward amount) was used, converging on an estimate of the amount of guaranteed reward that was equivalent to the subjective value in which the participants would be *indifferent* about choosing between the guaranteed or riskier choice. The first adjustment was half of the difference between the guaranteed and probabilistic rewards presented on the first trial, with each subsequent adjustment being half of the preceding adjustment. Figure 1 describes this "staircase" adjustment procedure in greater detail using the example of the condition with a 75% chance of receiving $2000. In the first trial, participants could choose between "$1000 for sure" or "$2000 with a 75% chance." If the participant chose "$2000 with a 75% chance", the choice on the second trial would be between "$1500 for sure" or "$2000 with a 75% chance." Alternatively, if the participant chose "$1000 for sure", the choice on the second trial would be between "$500 for sure" or "$2000 with a 75% chance." Subsequent trials would adjust the immediate reward such that the increase or decrease of the immediate reward would be half of the adjustment made in the previous trial. Thus, if the participant chose the probable reward first, and then chose the immediate reward during the second trial (which would now indicate "$1500 for sure"), the choices on the third trial would be between "$1250 for sure" or "$2000 with a 75% chance." Across all trials, the larger, probable reward (either $250 or $2000) remained fixed, and only the smaller, guaranteed reward was adjusted. Following the sixth and final trial of each condition, the subjective value of the probabilistic reward was estimated as the amount of the guaranteed reward that would be presented on the seventh trial. Before beginning, participants were also instructed that this task assessed personal preferences and that there were no correct or incorrect choices (see Green & Myerson, 2004).

Cued probability discounting. Following the baseline condition described above, the participants completed a probability discounting task, in which the values were accompanied by personally meaningful event cues (see Figure 2). Prior to the task, which followed the same procedures as the standard probability discounting condition, the participants were asked to identify six specific and personally meaningful events that were plausible given their expectations of their current and future selves. The participants were told to envision activities or events (e.g., appointments, anniversaries, outings) that could take place at any place and time, without any anticipated or imminent plans. This was specified to avoid temporal contiguity with the cued delay discounting condition (described in the following section). 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 considered engaging in or attending, either by themselves or with family and friends. In accordance with the Kwan et al. (2015) task, participants were asked to generate only emotionally neutral or positive events to avoid anticipatory distress. In addition, the cues were generated by the participants and chosen for the study when there would be financial incentives to use money if the events were to happen.

The cued condition proceeded in the same way as the standard (noncued) condition, except that each probability interval block began with one of the six personal cues, which were randomly assigned to the six probabilities for each of the $250 and $2000 reward conditions. Upon viewing the cued event, participants were encouraged to imagine the cued events in as much detail as possible. When the event or activity was in mind, participants pressed a button at their own pace to indicate that they were ready to proceed to the first block of the task. The personal cue remained at the top of the decision-making screen until the end of the block to ensure that the event remained active in the participants' minds and to reduce memory demands.

Delay Discounting Tasks

Standard delay discounting. Participants also completed a computerized version of an established delay discounting task (Green & Myerson, 2004) that has been utilized in recent years to examine the relationship between episodic memory and future imagining and other forms of future thinking in healthy and amnesic populations (Kwan et al., 2012; 2013; 2015). Again, participants were instructed that the task would assess preferences and that there were no correct or incorrect choices. Over a series of trials, participants were presented with hypothetical monetary values and asked to make choices between smaller, immediate reward amounts and larger, later reward amounts. For each of the two delay 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. The iterative, amount-adjusting procedure was analogous to the probability discounting procedures described above and used previously in other research studies (Green & Myerson, 2004; Kwan et al., 2012; 2013). After the sixth and final trial of each condition, the subjective value of the delay reward was estimated as the amount of the immediate reward that would be presented on the seventh trial.

Cued delay discounting. Following the baseline delay condition, participants completed the cued condition analogous to the paradigm used in Kwan et al. (2015). Prior to the task, which followed the same procedure as the standard delay discounting condition, participants were asked to identify seven personally specific and plausible events that were scheduled or likely to take place at the delay periods corresponding to those used in the task (i.e., in 1 week, 1 month, 3 months, etc.). The participants were instructed to generate personal cues that were emotionally neutral or positive future events, again 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. This contrasted with the cued probability discounting task, as the personal cues generated in this task were temporally contiguous with the delay intervals described, whereas the personal cues used in the probabilistic task were not tied to any specific time period. The cued condition proceeded in the same way as the standard (noncued) condition, except that each delay interval block began with one of the seven temporally contiguous personal cues. Upon viewing the cued event, participants were encouraged to imagine the cue events in as much detail as possible. When the event or activity was in mind, the participants pressed a button indicating that they were ready and proceeded to their first block of the task. The personal cue remained at the top of the decision-making screen until the end of the block to ensure that the event remained active in the participants' minds and to reduce memory demands.

Barratt Impulsiveness Scale

In addition to the two discounting tasks, participants were administered the Barratt Impulsiveness Scale (BIS-11, Patton, Stanford, & Barratt, 1995, see Appendix A). The BIS-11 is a widely administered 30-item self-report questionnaire that has been used in neuropsychological populations to evaluate everyday impulsive behaviours (e.g., Greve et al., 2001; but see Sellitto, Ciaramelli, & di Pelegrino, 2010, for an exception). The BIS-11 was administered at the end of the second session to avoid suggestive biases that may influence the way the decision-making tasks were conducted. As some of the tasks were probabilistic in nature and involve risky monetary decisions, it was important to identify whether participant preferences for the probabilistic choices related to their subjective impulsivity and risk-taking responses. The scale assesses three facets of impulsivity using the second-order factors embedded into the scale, which include motor impulsivity (e.g., “I act on the spur of the moment”), attentional impulsivity (e.g., “I often have extraneous thoughts when thinking”), and impulsive nonplanning (e.g., “I say things without thinking”).

Results

Probability discounting. Figure 3 displays the mean subjective values of the probabilistic rewards for the standard and cued conditions. To facilitate an observable comparison of the discounting curves for both the probability and delay discounting tasks, the subjective value of the probability tasks were plotted as a function of the odds against receiving the reward [$(1 - p)/p$, where p is the probability of receiving the reward], for both the $250 (top graph) and $2000 (bottom graph) amount conditions. This represents the change in the expected subjective value of a reward as the odds against receiving it increases. Note that when the odds against receiving a reward were greatest (i.e., 5% chance of receiving the larger reward), participants identified the subjective value of the probable reward to be more subjectively equivalent to a lower, guaranteed reward compared to when the odds against receiving were lower (i.e., 90% chance of receiving the larger reward). For both the cued and standard conditions, the mean subjective values indicated a steep discounting curve, in which the subjective value placed on the reward systematically decreased as the odds against receiving the larger reward increased.

Although there appeared to be a minor, observable difference between the two conditions in the $250 reward value, further analyses were conducted to parse out a possible effect of the personal cues. To investigate this, individual areas under the curve (AuCs; Myerson, Green, & Warusawitharana, 2001) were calculated for each of the six probabilities for each participant. The AuC is a theoretically neutral, normalized measure of the degree of discounting calculated using the subjective values for each data point, rather than a fitted curve. The values of the AuC ranges from 0.0 (steepest, maximal discounting) to 1.0 (no discounting indicated, Myerson et al., 2001). Probability discounting AuC data (Figure 4) were assessed using a 2 (Condition: Standard and Cued) x 2 (Reward Value: $250 and $2000) repeated measures analysis of variance (ANOVA). Performance was equivalent in the baseline (AuC $M = 0.14$, $SD = 0.09$) and cued conditions, $F(1,31) = 2.41$, $p = .13$, $\eta_p^2 = .07$. The ANOVA revealed a significant main effect of reward value, $F(1,31) = 13.33$, $p < .001$, $\eta_p^2 = .30$. Mean AuC difference between the two reward values was -0.07 (95% *CI* of the difference = -.11 to -.03). This magnitude effect, as it is commonly referred to in the discounting literature, reflects the fact that the larger (i.e., $2000, AuC $M = 0.15$, $SD = 0.12$) reward value was discounted more steeply than the smaller (i.e., $250. AuC $M = 0.18$, $SD = 0.13$) reward value (see Table 1 for this magnitude effect). There was no significant interaction between the conditions and the reward value, $F(1,31) = 0.69$, $p = .41$, $\eta_p^2 = .02$.

Delay discounting. Figure 5 presents the mean subjective values of the delayed rewards for the standard and cued conditions, plotted as a function of the time interval in months needed to wait to receive the reward, for both the $100 (top graph) and $2000 (bottom graph) amount conditions. Again, the mean subjective values of the cued and standard conditions indicated clear discounting, in which the subjective value placed on the reward systematically decreased as the delay to receive the larger reward increased.

An observed difference of the rates of discounting was found between the AuCs corresponding to the baseline and cued conditions of the delay tasks (Figure 6). To qualify this, a 2 (Condition: Standard and Cued) x 2 (Reward Value: $100 and $2000) repeated measures ANOVA was again conducted. Unlike the probability discounting findings, the ANOVA revealed a significant effect of condition, $F(1,31) = 57.60$, $p < .0001$, $\eta_p^2 = .65$, reflecting shallower discounting for the cued condition (AuC $M = 0.27$, $SD = 0.26$) compared to the standard condition (AuC $M = 0.69$, $SD = 0.28$) of the delay task. Bonferroni-adjusted comparisons indicated that the mean AuC value difference between the cued and standard condition was 0.42 (95% *CI* of the difference = .30 to .53). A significant main effect of reward value was also found, $F(1,31) = 12.40$, p < .01, $\eta_p^2 = .29$, such that the smaller reward value ($100, $M = 0.24$, $SD = 0.23$) was less than the larger reward value ($2000, $M = 0.46$, $SD = 0.33$). The AuC value difference between the larger ($2000) and smaller ($250) condition was 0.10 (95% *CI* of the difference = .04 to .16). As Table 1 shows, however, this magnitude effect is opposite in direction to what was observed in the probability discounting task; the larger reward value in the delay discounting task was discounted less steeply than the smaller delay amount. Again, no significant interaction was found between the conditions and the reward value, $F(1,31) = 2.34$, $p = .14$, $\eta_p^2 = .07$.

Self-reports of impulsivity (BIS-11). Participants' self-reports of impulsivity were compared to their performance on the standard and cued probability discounting task. No correlation to the total score on the BIS-11 was found with the rate of discounting, regardless of condition or reward amount, all *r*s < .30, *p*s > .05. Analyses of the second-order subscales of the BIS-11 indicated a significant negative correlation between the $2000 reward, standard probability task and the motor subscale, $r = -.44$, $p = .013$, 95% CI (-.72, -.04). All other subscales yielded nonsignificant correlation with task performance. Previous studies have suggested that a score above 74 on the BIS-11, approximately one standard deviation above the mean reported in Patton et al. (1995), indicates greater impulsivity, as well as greater variability in discounting performance, among other hallmarks that may represent causes for deviancy in discounting (e.g., aggression, low baseline arousal, faster cognitive tempo; Lawrence & Stanford, 1999); in practice, total scores between 52 and 71 are suggested to be within the normal limits of impulsiveness. A total score of 72 or above would classify an individual as highly impulsive; a total score lower than 52 would represent an overly controlled individual (see Stanford et al., 2009, for brief review). In the present study, one person was outside of the normal range of scores. When this individual was excluded from the analysis, the larger reward value in the standard condition became only marginally significant with the motor subscale, $r = -.36$, $p = .05$. All other correlations remained nonsignificant.

Discussion

The objective of this thesis was to determine whether episodic imagining of personally meaningful events, shown in previous studies to modulate intertemporal choice, would similarly modulate other forms of decision-making, such as atemporal probability discounting. In previous studies, it was unclear whether the modulatory effect seen in intertemporal choice tasks was due to the personal cues tied to the future-oriented decision. If the personal cues modulated discounting on the probability task, this would argue against the possibility that the cues induced episodic imagining in relation to receiving future reward values. Instead, and in line with our hypothesis, our results indicated that the effect of personal cueing was specific to the delay discounting task; there were no differences between the rates of probability discounting when personal cues were given and when they were not. This is suggestive of a more specific effect of cueing in potentially increasing meaningfulness or salience of the reward that is only seen in some forms of decision-making and not others.

Differing effects of personal cueing on intertemporal choice vs. risky decision-making: cognitive and neurological insights

The findings of no effect of cueing on probability discounting is in sharp contrast to the results of the delay discounting task, where personal cueing led to greater regard for larger future rewards. The latter result replicates findings from Kwan et al. (2015) and Palombo et al. (2015a) in middle-aged and older adults and supports previous evidence that episodic future thinking modulates future-oriented decisions in healthy young adults (Benoit et al., 2011; Peters & Büchel, 2010). The results from the current study suggest that personal cues alone may not be sufficient to affect reward-related decisions that do not have an obvious temporal component. The modulatory role of episodic simulation in decision-making may only govern a subset of value-based reward selection, such as those seen in intertemporal choice, and may not be generalized to probabilistic choices of risk. That is, intertemporal choice and risk-taking decisions may require separate cognitive processes that cannot be compared or viewed as intrinsically the same (Green & Myerson, 2004; 2013). This difference was surmised in a previous study by Peters and Büchel (2009) that identified distinct brain region signals during intertemporal choice and risky decision-making. A common system involving the ventral striatum and the orbitofrontal cortex was identified when participants in the study responded to both types of discounting tasks. This is not surprising given the conceptual proximity of these two tasks and the known role that the prefrontal cortex and striatum may serve in coding for the value and differences of decision outcomes (Hare, O'Doherty, Camerer, Schultz, & Rangel, 2008; Padoa-Schioppa & Assad, 2006; Peters & Büchel, 2009; 2010; Saez, Saez, Paton, Lau, & Salzman, 2017). Activity in these areas correlated with subject-specific estimates of stimulus value. More importantly, however, Peters and Büchel (2009) also described separate neural processes that point to a dissociation in decision-making mechanisms. Probability discounting involved the superior parietal cortex and middle occipital areas, which have previously been implicated in numeracy and magnitude processing (Peters & Büchel, 2009; Piazza et al., 2007). Specific to intertemporal choice, and not risky decision-making, was activation of the key regions of the brain that were previously attributed to self-referencing, self-projection, and future thinking. The authors noted that delay discounting activated the frontal pole and subregions of the posterior cingulate cortex, which are areas that have been identified alongside the hippocampus as central to episodic future thought and construction (Addis et al., 2007; Peters & Büchel, 2010; Schacter & Addis, 2009; Szpunar et al., 2007).

Evidently, these behavioural and neuroimaging findings imply that probability discounting is unlikely to be affected by similar factors like episodic imagining despite the similarities between uncertainty of a risky choice and the uncertainty of receiving a delayed reward (Rachlin & Siegel, 1994). If it is the case that temporality acts as a mediating factor in discounting of rewards, the interaction that is seen between future-oriented, personal cues and delay discounting may not be apparent on a task that does not require the individual to think about the future per se. To date, only one other study has extended the inquiry on the effect of episodic imagining to comparable forms of decision-making (Kaplan et al., 2016). In that study, personal cues were applied to a probability discounting task that also included an innate temporal component. Participants were shown an age-morphed representation of themselves prior to responding on a percent Likert scale how likely they would be to quit a hobby if it would permanently increase the chances of being healthy/unhealthy by a certain probability in 30 years. Contrary to the findings produced in this current study, Kaplan et al. (2016) showed that their procedure effectively changed the degree of probability discounting for both gains and losses. In the gains condition, analogous to receiving an uncertain amount of money in the present study, the participants were more likely to choose the larger probability and produce a shallower discounting curve.

The difference in results between the Kaplan et al. (2016) tasks and tasks used in the current study are surprising, but may describe key paradigm differences when a comparison of both is considered. In the earlier study, the authors cautioned that it was still unknown whether the same effect would be seen in probability discounting tasks alone, as their study utilized a combination of both temporal and probabilistic elements that made it difficult to pinpoint the source of the effect. The findings in this thesis suggests that there may be an interaction between personal cues and the temporal nature of future-oriented choices that is mediated by mentally experiencing specific future episodes. This effect does not appear in risky decisions, such as a stand-alone probability discounting task. Furthermore, the former study's design tapped into episodic future thinking extensively; in their task, participants looked at aged depictions of themselves and were asked questions directly about their later selves, 30 years into the future. In our study, we specifically asked our participants to imagine plausible scenarios that were not set to a specific time. In this way, we attempted to control for the influences that the participants' temporal concerns may have towards how they make their choices. If the participants had shown a cueing effect, this would have been strong evidence that the constructive properties of episodic imagining are sufficient in facilitating broad decision-making in healthy adults. In the context of the findings here, at least for reward gains, it appears that the effects of episodic imagining are circumscribed to temporal discounting. What remains unknown is understanding the neurological significance of these findings.

Is there a role of the hippocampus in compensatory decision-making? Extension to amnesic individuals

The current thesis extends our understanding of the limits to which personal cueing may serve as a compensatory strategy in making choices, and highlights the limits in which theoretical evidence supporting the general role of the hippocampus in decision-making may be described in actual practice (see Palombo et al., 2015b, for review; Wimmer & Shohamy, 2011). The hippocampus' role in moderating new information and retrieving episodic memory has been greatly described in the literature. Due to its flexibility, the hippocampus is particularly suited to support our ability to construct representations of future or novel episodic experiences (Schacter & Addis, 2009). Some have speculated that the interaction between the hippocampus and its contributions to episodic imagining may serve a critical role in goal-directed behaviour that responds to episodic insight (Boyer, 2008). A point worth considering is understanding the extent to which the hippocampus is actively engaged in this form of human cognition. One proposition is that the hippocampus is responsible for integrating a temporal template. If the hippocampus is necessary for constructive episodic simulation, this would mean that episodic details from past experiences and memories are extracted and flexibly recombined for us to generate and consider future possibilities and outcomes (Schacter & Addis, 2007). Alternatively, it is possible that the hippocampus is needed for constructing and binding details more generally. Our abilities to imagine episodic details, whether it is to remember the past, think about the future, or generate sequences of events in an atemporal fashion, may be served by a greater emphasis from the hippocampus in constructing and maintaining complex, coherent information (Addis et al., 2004; Hassabis & Maguire, 2007; Rosenbaum et al., 2009).

Previously, Kwan et al. (2013) showed that some amnesic patients with hippocampal damage are nonetheless able to make both future-oriented and risky financial decisions at similar capacities to healthy adults. A follow-up study by Kwan et al. (2015), whose results were replicated in younger adults in this thesis, showed that older adults and two of the six amnesic individuals showed steeper delay discounting when cued to think about future personal experiences. As discussed in that study, the two patients differed from the rest of the amnesic participants on a number of variables: the severity of their lesions; the extent of their episodic future thinking capability; and the effect that cueing had on future-oriented decisions. One of these two individuals, Patient D.A., had widespread MTL damage, possessed average impairments in episodic future imagining, but showed a low average cueing effect on delay discounting. In contrast, another patient, D.G., who likely had much more circumscribed lesions due to the etiology of his amnesia (anoxia), showed the opposite pattern of results; he possessed average episodic future imagining abilities, but an above average cueing effect. Interestingly, these two patients also produced unique patterns of performance on standard versions of the probability discounting task (Kwan et al., 2013). D.A. showed shallow discounting, whereas D.G. performed indistinguishably from controls. Although individual variability exists in the discounting literature (Odum, 2011), less clear is how these patients may fare in other forms of decision-making when presented with environmental manipulations. If it is the case that hippocampal structural integrity is necessary for episodic construction of imagined events, then it is expected that the hippocampal patients should not show any variability when provided with personal cues. If there are differences, it is also possible that those patients employed a different strategy than controls to achieve typical discounting, and that other patients who did not show a benefit of cueing also achieve typical discounting performance via a different route, even in the absence of personal cues. This was suggested by Kwan et al. (2012; 2015), who presented as a possibility the reliance on semantic-based strategies to delay discounting performance in amnesic as compared to control participants. If so, a difference in strategy might also emerge in probability discounting when more concrete, specific events are made available, such that patients but not controls would show a shift in probability discounting behaviour in the presence of cues.

Preliminary findings with the two patients discussed above, who completed the same cued probability task, but not reported in this thesis, concur with this latter suggestion. The performances of D.A. and D.G. on this task were compared to a sample of age- and education-matched healthy older adults. Unlike their healthy control counterparts, both amnesic individuals showed some effect of personal cueing with the probability task. The suggestions that there may be a cueing effect seen in patients, but not in healthy controls is surprising, and may suggest differences in strategy due to the patients' episodic memory impairment and lack of hippocampal integrity. Previous studies have also reported the performances on a standard probability discounting task and cued and standard delay discounting tasks for these two amnesic individuals (Kwan et al., 2013; 2015). In those earlier studies, when asked to describe strategies used to make the monetary-based decisions, D.A. reported using strict economic strategies that considered inflation and interest rates. In the preliminary findings, he made similar responses, describing his choices as "current risks and rewards." This commentary relates very much to D.A.'s previous educational and vocational background in finance, and suggested a reason as to why his discounting curves were generally shallower than other participants. In D.G.'s case, he described the personal cues as helping him to orient to the financial incentives for each event. The variability within these two amnesic patients are likened to the idiosyncratic responses commonly seen in intertemporal choice (e.g., Kwan et al., 2012; Peters & Büchel, 2010). As Boyer (2008) alluded to, an adaptive feature of episodic imagining is to encourage future-oriented behaviour. In delay discounting, this reduces the steep discounting of future rewards. It is possible that in probability discounting, rather than assisting the individual to choose future options, the personal cues may serve a role in orienting preferences toward more adaptive choices regardless of time. In line with these findings, probability discounting, like delay discounting, may be analogous to relatively stable personality traits (Harty, Whaley, Halperin, & Ranaldi, 2011; Kirby, 2009; McCarthy et al., 2016; Odum, 2011). Given this variability, testing participants multiple times on each paradigm would be important for future research. Further testing with more hippocampal amnesic patients will also be useful in determining whether the results seen in these two select individuals are merely idiosyncratic.

Separating types of discounting as different constructs of impulsivity

The findings presented here also raise a point of discussion regarding the relationship between risky decision-making and intertemporal choice. A motivation for this study was that the two discounting tasks share inherent similarities, such that it might be reasonable to assume probability discounting and delay discounting occupy two sides of the same coin, highlighted by shared traits of impulsivity. In the behavioural economics literature, earlier accounts had presumed that intertemporal choice and risky decision-making shared a common choice behaviour related to uncertainty (Green & Myerson, 1996; Rachlin, Raineri, & Cross, 1991, Weber & Chapman, 2005). It was believed that uncertainty of an event (i.e., the chance of receiving the financial outcome in probability discounting) was conceptually equivalent to having to wait for a distal reward (i.e., the delay of receiving the financial outcome in intertemporal choice) (Wakslak, Trope, Liberman, & Alony, 2006). It would make sense that individuals who are risk-takers would also show an inability to delay gratification. In the context of discounting, impulsive individuals would possess shallower probabilistic functions and steeper delay discounting curves. In the current study, healthy young adults were tasked with both the cued and noncued conditions of the probability and delay discounting task. When confronted with risky, probabilistic options, participants generally reserved their decisions to riskier (shallower discounting) options when the reward value was smaller, but selected safer (steeper discounting) options when the reward value was larger. As predicted, the opposite magnitude effect was produced by the participants during the delay discounting tasks; larger delayed rewards were discounted at a lower rate than were smaller values. Indeed, findings from both sets of discounting tasks describe opposing magnitude effects that are consistent with some speculations of a plausible parallel process (Green et al., 1999; Myerson, Green, Hanson, Holt, & Estle, 2003) where delay and probability discounting show a theoretically negative correlation.

If the general assumption holds true that choosing larger, delayed rewards and accepting smaller, more likely financial incentives can be paired together to describe self-control and impulsivity, this would lend credence to the single-process view that suggests the same variables that can predictively influence intertemporal choice can be extended to probability discounting as well (Prelec & Loewenstein, 1991; Rachlin et al., 1991). The findings of a null effect highlight the possible dissociation separating delay and probability discounting as constructs despite the quantifiable similarities used to describe these two measures (Green & Myerson, 2004). The findings that personal cues do not generate the same pattern of response for both types of discounting challenge the classic point that both types of discounting emerge from the same behavioural mechanism. Instead, it further supports the alternative view, which posits that different forms of discounting do not represent the same underlying traits of impulsivity (Green & Myerson, 2013). This was confirmed by the self-report measure used in our study (BIS-11) which showed that there were no relationships between the resulting rates of discounting on the probability task and individual traits of impulsivity. It is possible that the BIS-11 tapped into a general construct of impulsivity, whereas probability discounting is more closely associated with risk-taking. Risk-taking, which can be defined as a strategic preference for selection of outcomes with low odds and a form of sensation seeking (Floden et al., 2008; Zuckerman, 1993) may, therefore, be dissociated from the distinct, but overlapping construct of impulsivity.

A more general consideration is that an inability to directly relate impulsive behaviour to the rates of discounting highlights the difficulties of extracting individualized impulsive personality traits from self-reports assessing the participants' own awareness of behaviour. Recently, MacKillop et al. (2016) found that impulsive personality traits examined by the BIS-11 and other psychometric measures showed some associations with domains of impulsive choice (i.e., intertemporal choice and rates of discounting), but had little correlation with other behavioural actions that have previously been studied as observations of impulsivity. The authors cautioned viewing impulsivity as a single construct that could be identified by current unidimensional measures. Instead, they suggested that impulsivity is more likely to be defined by overlapping dimensions that are diverse and quite distinct from each other, even amongst healthy individuals. This is consistent with previous findings in both clinical and nonclinical populations that show little empirical evidence to support a relationship between behavioural laboratory tasks and self-reports of impulsivity (Cyders & Coskunpinar, 2011; MacKillop et al., 2016; Schooler, 2002).

Limitations and Future Considerations

A limitation that emerged during post-task interviews was indicated by a small group of participants who remarked on a perceived dissociation between the self-generated cues and the presentation of the probabilistic choices. Unlike the delay discounting task, where the personal cues were temporally contiguous to the delay of the larger reward, the events in the cued probability task were randomized across the probabilities and were instructed to be unplanned and not related to an instance in the lives of the participants. Given the temporal proximity in which the standard and cued tasks took place, it is therefore surprising that a small sample of participants had the same disconnected view. Although this did not influence the present findings, and provides stronger evidence in support of the results given that the cues may have been derived from either past experiences or future goals, a follow-up study can be conducted to see whether observable differences in the cueing effect occur if the cues in the probability tasks were explicitly tagged to the larger, uncertain rewards. One way of modifying the task is to indicate to the participant that the cost of the event or activity triggered from his or her personal cue is equivalent to the larger reward value presented. Using the cue generated in Figure 2 as an example, the participant would then be asked to choose between $125 “for sure” or $250 with a 75% chance to use on a ticket to go whale watching.

It is possible that in the previously described intertemporal choice tasks, the personal cues rely on an internalized “priming scaffold” mechanism that orients participants to consider the future more and discount delayed rewards less. One recent study showed that future-oriented words reduced discounting of future payoffs in healthy individuals compared to present-focused and nontemporally associated words (Sheffer et al., 2016). Inexplicably, the finding of a priming effect has been consistently used in the literature involving retrieval of autobiographical memory and future imagining. Imaginability often elicits easier access to autobiographical retrieval or construction. Cues that are more concrete and can be visualized predict how well participants recollect events and draw on experiences (Rubin & Schulkind, 1997; Williams, Healy, & Ellis, 1999). Recently, Kwan, Kurczek, and Rosenbaum (2016) found that amnesic patients showed a reduction of episodic simulation impairment when presented with elaborative cues compared to a standard autobiographical retrieval paradigm like Galton-Crovitz cueing. For the probability discounting task, it is possible that the cues used in our study are restricted in plausibility and meaningfulness as they were not tied to a specific future time period. This may further limit the generalizability of the present study as the same cues were not used in both the probability discount and delay discounting tasks. Whether explicit cues, either tagged to a reward value or temporal event, may show the same effect for probability discounting remains an interesting next step for further investigation.

With respect to the preceding limitation and the previous discussion about individual effects of discounting, there may also be a need to examine these two thoughts together in greater detail. In our unstructured, post-task interview with participants, anecdotal evidence supported two overarching strategies that participants may have used to respond to these tasks, particularly for the delay discounting paradigms. Some participants chose a more conservative, “bird in hand” approach, preferring immediate payoff to be ready for a future event. Other participants chose the delayed option in anticipation of having to use money at the time of the event. It was unclear whether these strategies were utilized when participants responded to the probability task, but such responses speak to qualitative differences in individual influences on decisions that are beyond the scope of the present study. This aligns with previous findings by Kwan et al. (2013; 2015) suggesting that even amnesic individuals may still retain certain characteristics that are captured in their performance on both delay and probability discounting procedures. A future course of study may be to combine qualitative and quantitative research comparisons in a mixed-methods approach to distinguish covert heterogeneity within groups (see Johnson, Onquegbuzie, & Turner, 2007, for a review on this approach; see Fleming, Strong, & Ashton, 1996; and Thompson, Stopford, Snowden, & Neary, 2005, for examples in the neuropsychological literature).

A final methodological limitation to consider is the interpretation of the correlational analysis used to compare the behavioural observations on the probability discounting task with the participants' subjective impulsivity. The correlational analyses between the probability discounting AuC outcomes and the BIS-11 measure showed a nonsignificant relationship across both conditions, which may be in line with the suggestion that the scale was not truly measuring the construct underlying the probability discounting task. A cautionary note of overinterpretation must be made, however. The BIS-11 was primarily used as a screening measure to avoid recruiting participants with inherent traits of impulsiveness. The findings in our study, while surprising, may reflect a homogeneity of our participants. Additionally, the stability of traditional correlational analyses largely depends on the sample size. The overall findings were based on only 32 participants, with one individual outlier removed in the final correlational analysis, suggesting that the number of participants in the current study may be too modest to fully appreciate the relationship between the outcomes derived from the probability tasks and the individuals' subjective impulsiveness. Replication with a much larger sample size is warranted and necessary, with previous findings suggesting that correlations stabilize in typical research studies when *n* approaches 250 participants (Schönbrodt & Perugini, 2013). Despite this possible concern with the correlational analyses, the significant discounting effects in the current study still hold considerable merit. In the current study, the magnitude effects for both the delay and probability discounting tasks were medium (.29 to .30), while the effect size of the difference between cued and noncued delay discounting was particularly robust (.65 in this study), replicating multiple studies that showed a role of personal cueing in delay discounting (Benoit et al., 2011; Kwan et al., 2015; Peters & Büchel, 2010). Thus, our findings captured the potential effect that personal cueing plays in different forms of decision-making, contributing to the ongoing research in the discounting literature.

Concluding Remarks

The goal of the current thesis was to extend our knowledge of the processes underlying episodic imagining and decision-making, and how it may be engaged with the current precepts in the literature. Research in this domain has attempted different modifications to these cues. These studies have come to the same conclusion that personal cueing initiates a modulatory effect in intertemporal choice. Less clear is whether cueing effects are observed in decision-making that is not temporally oriented. This thesis used a probability discounting task comparable to a previously used delay discounting paradigm (Green & Myerson, 2004; Kwan et al., 2015). Young adults completed standard and cued conditions of both probability and delay discounting tasks. The results indicated that the two tasks were differentially sensitive to personal cues. When cued to vividly imagine events that were temporally contiguous to the delayed rewards in the intertemporal choice task, the participants replicated the cueing effect seen in Kwan et al. (2015) and other studies producing discounting curves that were much shallower compared to the baseline condition. By contrast, virtually no difference in performance was observed between the standard and cued conditions of the probability discounting task, suggesting that there may be an interaction at play between the personal cues and the temporal nature of the delay discounting tasks that is not evident in probability discounting.

The results from the current study were inconsistent with those from a recent study conducted by Kaplan et al. (2016), in which episodic future thinking was investigated alongside a discounting paradigm that featured a risky, probabilistic procedure. Their "proof of concept" study showed that personal cueing extended to other domains of decision-making when tagged with a temporal component. Contrary to these preliminary findings, this thesis showed that personal cueing may not be sufficient for a standard, probability task. Rather, the null findings in healthy individuals suggest that personal cueing is involved in a more specific form of decision-making. In our ability to construct consequential outcomes about the future, it appears that knowing when the choice will be in effect is equally important. Further research will need to be conducted to better understand the interaction at play between episodic imagining and the temporal nature of the delay discounting task that appears to be modulated by our abilities to remember the past and imagine the future in some capacity.

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Table 1

Mean (and SD) Area under the Curve (AuC) of Probabilistic and Delayed Rewards

	Probabilistic Amount		Delayed Amount	
Reward	Small $250	Large $2000	Small $100	Large $2000
Standard	0.17 (0.09)	0.11 (0.08)	0.24 (0.23)	0.31 (0.28)
Cued	0.20 (0.13)	0.12 (0.13)	0.61 (0.29)	0.75 (0.26)

Note: Standard deviations are given in parentheses.

Figure Captions

Figure 1: Iterative adjustment procedure (e.g. for probability discounting). Across six trials for each probability for both reward values, participants selected between a smaller, guaranteed adjusting amount and a fixed larger, probable amount. The subjective value for the specific reward value and probability was calculated as the guaranteed value that would appear for the seventh trial. The subjective value is described as the adjusted, guaranteed reward value that is deemed to be subjectively equivalent to the larger, probabilistic reward value. The same adjusting procedure is used in probability and delay discounting across both cued and standard conditions.

Figure 2: Cued probability discounting task. Participants were presented with a previously generated, personally meaningful cue that was not set to a specific time and were asked to imagine the experience in as much detail as possible. Next, they were presented with two hypothetical rewards and indicated their choice between the smaller, "for sure" reward and the larger, uncertain reward while having the cue continuously presented throughout the task and decision phase.

Figure 3: Probability discounting. Relative subjective value of rewards is plotted as a function of odds against (1-*p*/*p*) receiving a reward. This represents the change in the expected subjective value of a reward as the odds against receiving it increases. The upper graph shows the data from the $250 reward condition, and the lower graph shows the data from the $2000 reward condition.

Figure 4: Comparison of means for the area under the curve (AuC) index used to measure the rate of discounting in the standard and cued probability discounting tasks, for both the $250 and $2000 reward conditions. Error bars indicate SEM.

Figure 5: Delay discounting. Relative subjective value of rewards is plotted as a function of delay (in months) in receiving a reward. The upper graph shows the data from the $100 reward condition, and the lower graph shows the data from the $2000 reward condition.

Figure 6: Comparison of means for the area under the curve (AuC) index used to measure the rate of discounting in the standard and cued delay discounting tasks, for both the $100 and $2000 reward conditions. Error bars indicate SEM.

Figure 1

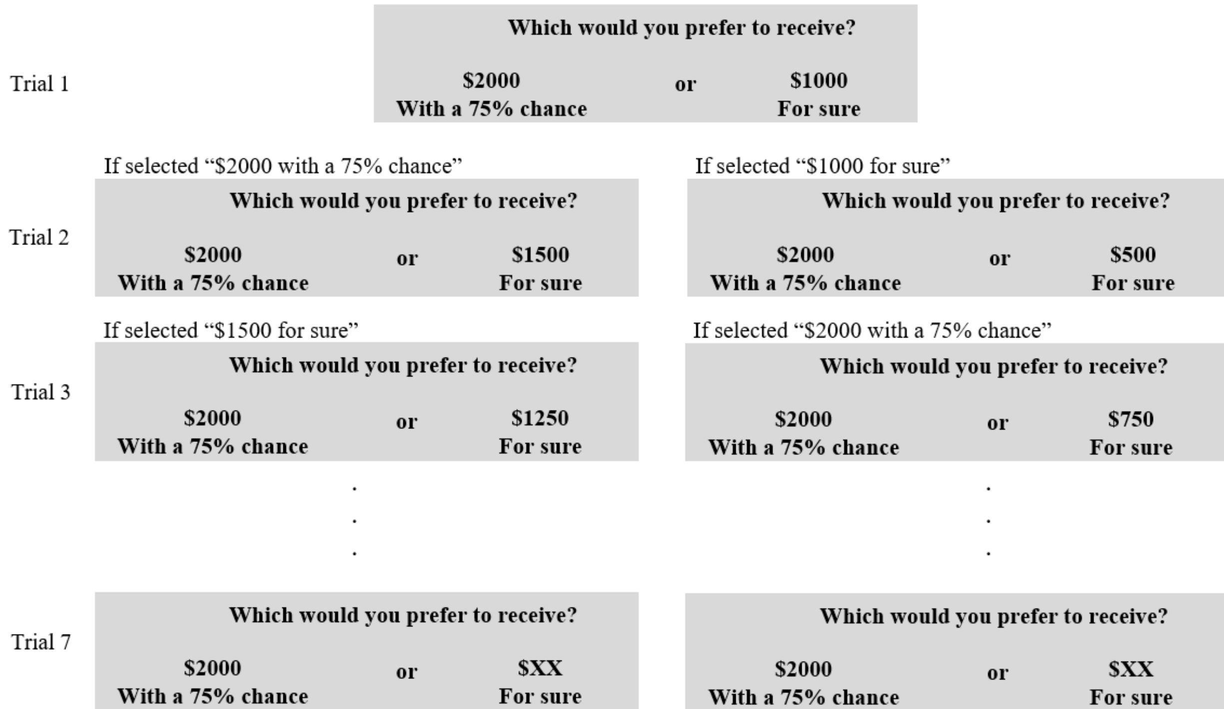

Trial 1
Which would you prefer to receive?
$2000
With a 75% chance
or
$1000
For sure
If selected “$2000 with a 75% chance”
If selected “$1000 for sure”
Trial 2
Which would you prefer to receive?
$2000
With a 75% chance
or
$1500
For sure
Which would you prefer to receive?
$2000
With a 75% chance
or
$500
For sure
If selected “$1500 for sure”
If selected “$2000 with a 75% chance”
Trial 3
Which would you prefer to receive?
$2000
With a 75% chance
or
$1250
For sure
Which would you prefer to receive?
$2000
With a 75% chance
or
$750
For sure
Trial 7
Which would you prefer to receive?
$2000
With a 75% chance
or
$XX
For sure
Which would you prefer to receive?
$2000
With a 75% chance
or
$XX
For sure

Figure 2

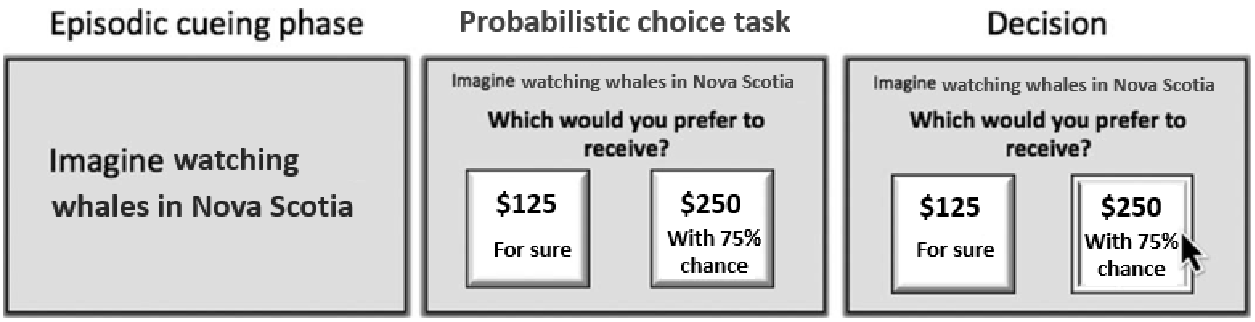

Episodic cueing phase
Probabilistic choice task
Decision
Imagine watching whales in Nova Scotia
Imagine watching whales in Nova Scotia
Which would you prefer to receive?
$125
For sure
$250
With 75% chance
Imagine watching whales in Nova Scotia
Which would you prefer to receive?
$125
For sure
$250
With 75% chance

Figure 3

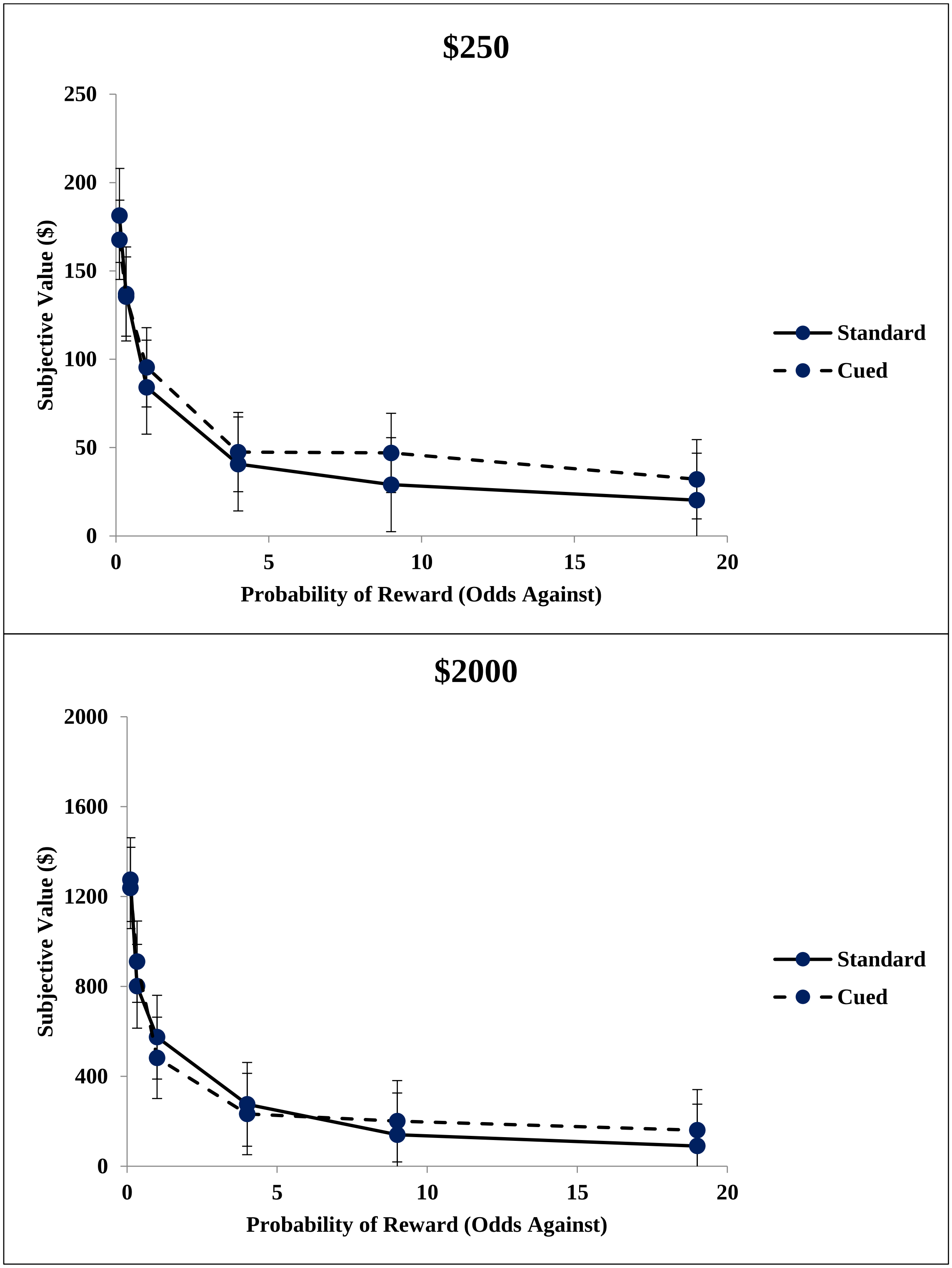

$250
250
200
150
100
50
0
Subjective Value ($)
0
5
10
15
20
Probability of Reward (Odds Against)
Standard
Cued
$2000
2000
1600
1200
800
400
0
Subjective Value ($)
0
5
10
15
20
Probability of Reward (Odds Against)
Standard
Cued

Figure 4

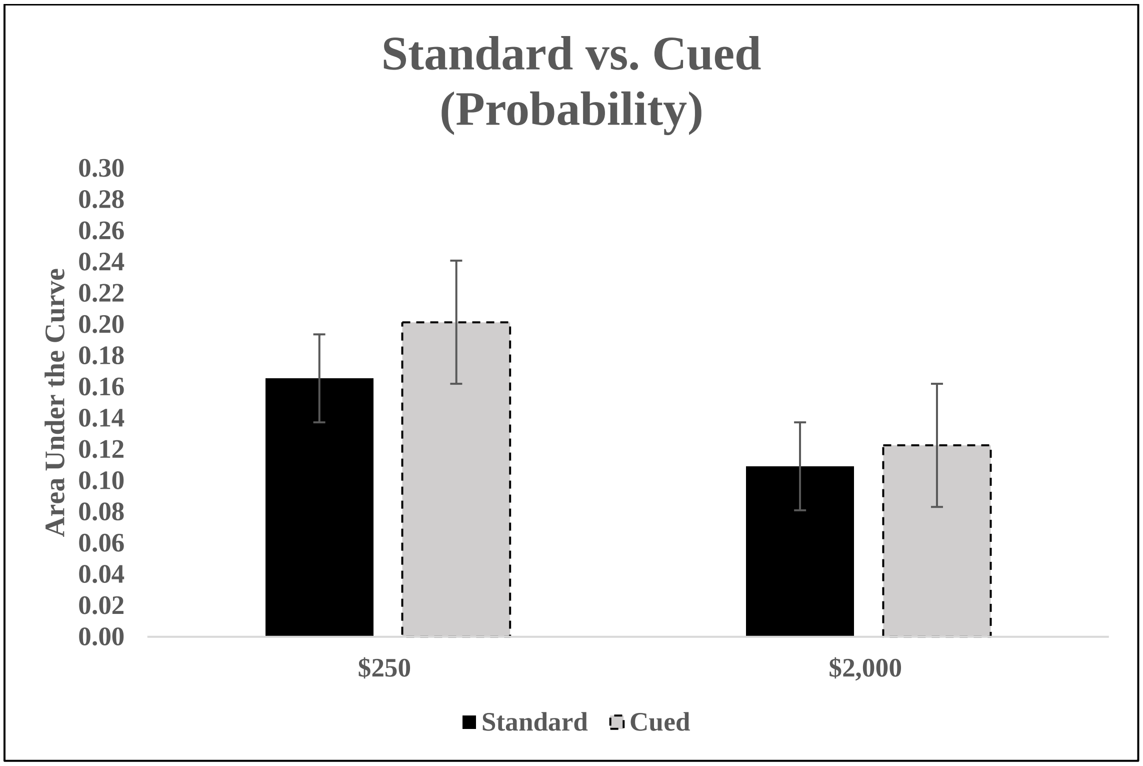

Standard vs. Cued
(Probability)
Area Under the Curve
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
$250
$2,000
Standard
Cued

Figure 5

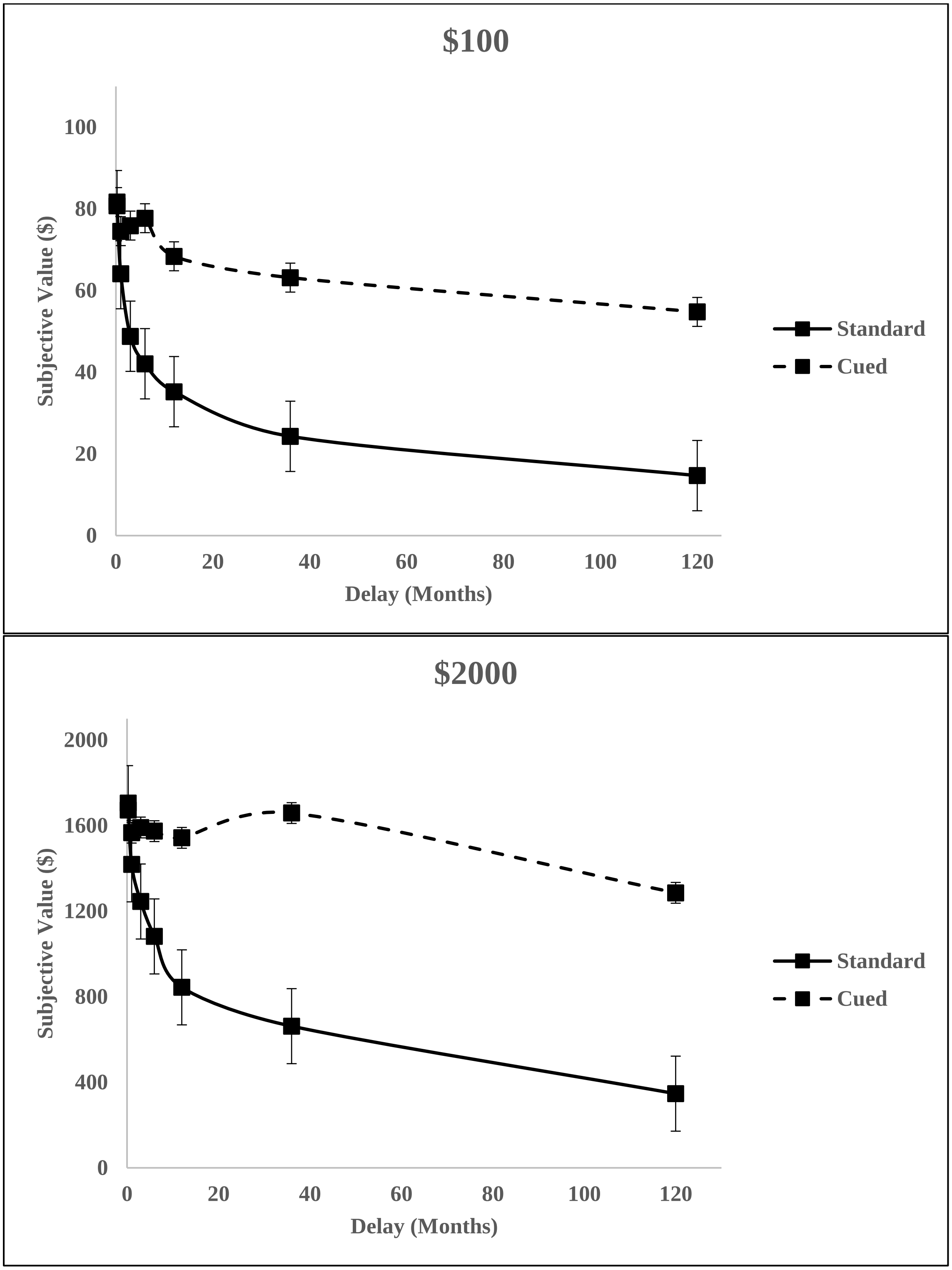
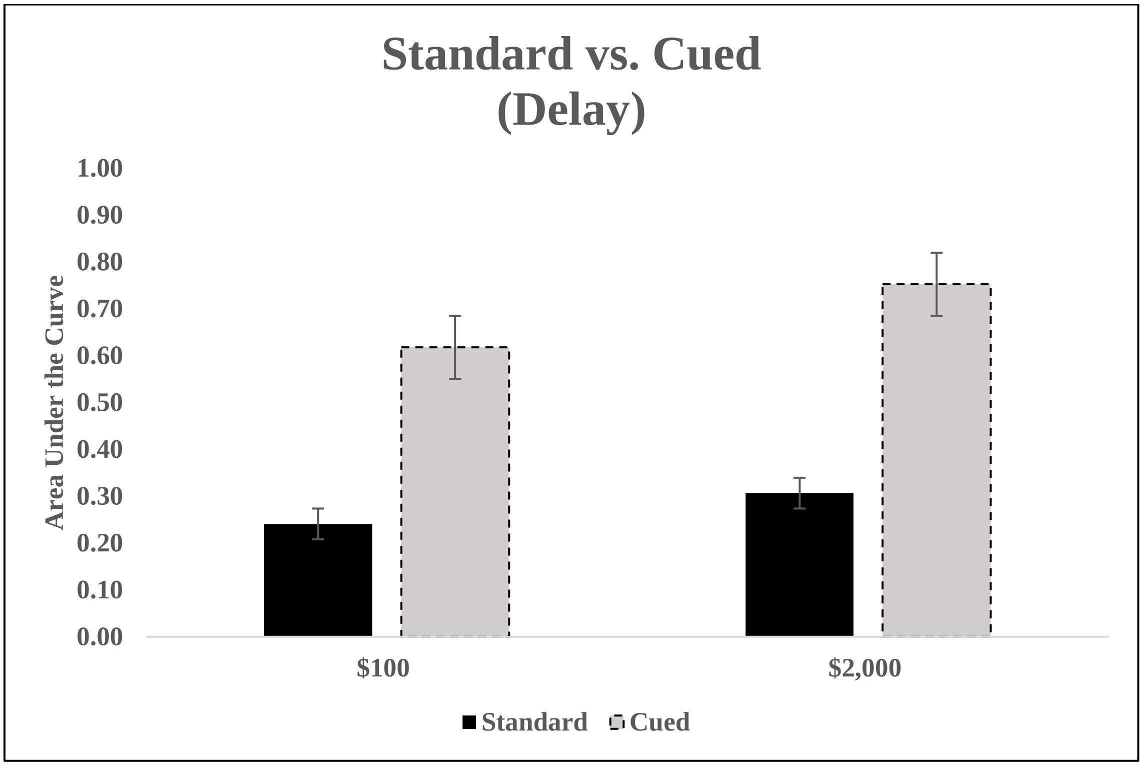

$100
Subjective Value ($)
100
80
60
40
20
0
0
20
40
60
80
100
120
Delay (Months)
Standard
Cued
$2000
Subjective Value ($)
2000
1600
1200
800
400
0
0
20
40
60
80
100
120
Delay (Months)
Standard
Cued

Figure 6


Standard vs. Cued
(Delay)
Area Under the Curve
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
$100
$2,000
Standard
Cued

Appendix A

Barratt Impulsiveness Scale (BIS-11, Patton et al., 1995)

DIRECTIONS: People differ in the ways they act and think in different situations. This is a test to measure some of the ways in which you act and think. Read each statement and put an X on the appropriate circle on the right side of this page. Do not spend too much time on any statement. Answer quickly and honestly.

① Rarely/Never ② Occasionally ③ Often ④ Almost Always/Always

1	I plan tasks carefully.	①	②	③	④
2	I do things without thinking.	①	②	③	④
3	I make-up my mind quickly.	①	②	③	④
4	I am happy-go-lucky.	①	②	③	④
5	I don't "pay attention."	①	②	③	④
6	I have "racing" thoughts.	①	②	③	④
7	I plan trips well ahead of time.	①	②	③	④
8	I am self controlled.	①	②	③	④
9	I concentrate easily.	①	②	③	④
10	I save regularly.	①	②	③	④
11	I "squirm" at plays or lectures.	①	②	③	④
12	I am a careful thinker.	①	②	③	④
13	I plan for job security.	①	②	③	④
14	I say things without thinking.	①	②	③	④
15	I like to think about complex problems.	①	②	③	④
16	I change jobs.	①	②	③	④
17	I act "on impulse."	①	②	③	④
18	I get easily bored when solving thought problems.	①	②	③	④
19	I act on the spur of the moment.	①	②	③	④
20	I am a steady thinker.	①	②	③	④
21	I change residences.	①	②	③	④
22	I buy things on impulse.	①	②	③	④
23	I can only think about one thing at a time.	①	②	③	④
24	I change hobbies.	①	②	③	④
25	I spend or charge more than I earn.	①	②	③	④
26	I often have extraneous thoughts when thinking.	①	②	③	④
27	I am more interested in the present than the future.	①	②	③	④
28	I am restless at the theater or lectures.	①	②	③	④
29	I like puzzles.	①	②	③	④
30	I am future oriented.	①	②	③	④