

Does thinking about the past reduce temporal discounting? An investigation into the effects of episodic thought on intertemporal choice

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Thesis directed by Professor Marie T. Banich

Humans show a preference for present rewards over delayed rewards, a phenomenon known as temporal discounting (TD). TD, of perennial interest because of its violation of rational economic theory, is associated with poor outcomes such as drug addiction and perhaps even global warming. Recent research has shown that episodic future thinking can reduce temporal discounting, possibly by modulating subjective valuation processes through imagery-based operations supported by the medial temporal lobe and connecting structures. Interestingly, a growing body of additional research suggests that episodic memory and episodic future thought share similar cognitive processes and neural mechanisms. Given these findings, an immediate question is whether episodic memory can also reduce temporal discounting. To investigate this question, we created a behavioral paradigm whereby participants performed intertemporal choice trials, but each trial was primed by either a brief period of episodic past thought, episodic future thought, or a non-episodic imagery control condition. In line with previous findings, participants discounted future rewards compared to present rewards and showed wide inter-individual variability in their discounting rates. However, when

comparing discounting rates between the three conditions, results revealed that episodic memory reduced TD more than episodic future thought and the imagery control condition. In contrast, no differences in TD were observed between the episodic future thought condition and the control condition. Given that the episodic past thought condition was associated with higher self-reported imagery than the episodic future thought condition, these findings suggest that basic episodic imagery processes might play an important role in modulating intertemporal decision-making.

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Introduction

A typical decision-making scenario involves choosing between options that vary in the delay at which they will be delivered. This process, referred to as intertemporal choice, requires weighing tempting short-term rewards against long-term goals. For example, if you are at a store and see a shiny new gadget, you must weight the reward of buying it against long-term goals such as investing that money in order to happily retire later in life. Unfortunately, humans show a preference for immediate rewards over future ones, a phenomenon known as temporal discounting. Temporal discounting is of perennial interest because of its violation of rational economic theory, which can lead to poor outcomes such as credit card debt or even global warming. Furthermore, deficiencies in intertemporal choice have been linked to a variety of disorders such as substance abuse and attention deficit hyperactivity disorder (ADHD). Fortunately, the last decade has seen a leap in our understanding of neural decision-making mechanisms which economists hope can improve behavioral prediction and psychologists hope can improve decision-making in those with mental disorders as well as healthy individuals.

In particular, recent research has seen a surge of interest in the contribution of episodic future thought, along with corresponding activity in the medial temporal lobe, when choosing delayed rewards. In the present study, we seek to further specify the role of episodic future thought in reducing temporal discounting by comparing it with a very similar process: episodic memory or episodic past thought. In the present manuscript, I will first review behavioral findings on human temporal discounting and its underlying neural mechanisms with a focus on the contribution of episodic future thought. Next, the

manuscript reviews recent findings on episodic future thought and compares it with episodic past thought. Finally, I will describe the present experiment and its results, ending with a discussion on its significance on the existing literature.

Behavioral findings

The primary behavioral finding in intertemporal choice research is temporal discounting. Temporal discounting is the phenomenon that humans, as well as animals, behave as if rewards that are available in the future are worth less than awards available immediately. In other words, the subjective value of rewards available in the future is discounted as time until delivery increases. This behavior is very robust and often leads to people choosing smaller rewards available immediately over larger rewards available in the future. For example, if faced with 100 dollars now and 120 dollars in one month, a discounter might pick the smaller presently available reward. In this case, it would be said that the subjective value of the future reward, discounted by time, was lower than the subjective value of the immediately available reward.

Modeling the rate and function with which humans discount future rewards with time has been a primary focus of research on intertemporal choice. In particular, by giving subjects a range of combinations of reward values and future reward delays, it is possible to fit a function and discount parameter, k , to their preferences. It is of particular interest to economists to compare the extent to which that function deviates from the normative model of temporal discounting. According to a discounted utility model, future rewards should be discounted at an exponential rate with time (Samuelson, 1937). Exponential discounting is consistent with the assumption that future rewards are less likely to occur

and thus have reduced utility; moreover, exponential discounting results in consistent preferences over time, as the rate of discounting is constant per period.

A vast literature on human temporal discounting suggests, however, that people discount rewards hyperbolically (Frederick, Loewenstein, & O'donoghue, 2002).

Hyperbolic discount functions decay at a more rapid rate in the short run than in the long run, such that hyperbolic discounters are more impatient when choosing among short-term tradeoffs than long-run tradeoffs (Berns, Laibson, & Loewenstein, 2007). In other words, the difference in subjective value between a reward available now and a reward available in one week is greater than the difference between a reward available in one week and one available in two. Hyperbolic discounting has been blamed for a variety of unwanted behaviors, including reversal of preferences – the phenomenon of making a decision only to change it in the future (Ainslie & Herrnstein, 1981). For example, one might choose to stop unnecessary spending this year only to reverse that decision and splurge on an attractive but unnecessary gadget at the store.

Another widely studied aspect of intertemporal choice is the wide variability observed between people. The study of individual differences in temporal discounting is facilitated by the robust model based analyses previously mentioned; such precise models allow for comparisons between minute changes between individuals (Peters & Büchel, 2011). Two important types of trait variability exist in intertemporal choice. Firstly, even among healthy participants, rates of discounting vary widely and have been found to differ among people with different personalities (Hirsh, Morisano, & Peterson, 2008). These inter-individual differences have been found to quite robust and stable over time. Second,

specific population groups have been found to show markedly steeper discounting functions. In particular, people with ADHD (Barkley, Edwards, Laneri, Fletcher, & Metevia, 2001), substance-abuse disorders (Coffey, Gudleski, Saladin, & Brady, 2003), and compulsive gamblers (Petry & Casarella, 1999) discount rates faster than healthy adults, showing less patience for delayed rewards. Steeper discounting has also been associated with lower IQs and related outcome measures such as scholastic performance (Shamosh et al., 2008). This wide variation in discounting behavior and its impact on real-world outcomes has led researchers to create unified frameworks of intertemporal choice which try to account for the range of behaviors discussed above with a few underlying variables (Berns, Laibson, & Loewenstein, 2007). For example, one framework proposes that three separable factors, anticipation, self-control and representations, account for the differences observed. However, others have attested that other factors (such as future orientation), better account for inter-individual variability (at least in development; see Steinberg et al., 2009).

Neural Mechanisms

In cognitive neuroscience, there has been a great interest in using functional neuroimaging to understand the neural underpinnings of intertemporal choice. This attempt has shown promise in helping create a unified framework for understanding the basic mechanisms underlying intertemporal choice, thus illustrating the various points where this mechanism can break in people with disorders or vary among healthy individuals. However, just as there has been difficulty in arriving at a unified framework behaviorally, debate still rages regarding the function of the neural mechanisms implicated.

Two processing stages have been proposed: valuation, which is the neural computation and representation of the subjective values of available decisions options, and choice, which are the processes supporting selection of one of the options. (Peters and Buchel, 2011). Within these processes, the valuation network supports the representation of value, while cognitive control regions support conflict resolution, strategy adaptation and self-control. Moreover, areas such as the medial temporal lobe support episodic future thought which is thought to increase the representational value of future rewards.

Valuation

Research in cognitive neuroscience has supported the idea that mesolimbic dopaminergic regions, in particular the ventral striatum (VS) and the ventromedial prefrontal cortex (vmPFC) play a major role in calculating and representing the subjective incentive value of available options across a variety of reward types. Neurons in these areas have been shown to also activate for the consumption of primary rewards in monkeys and were initially thought to represent the value of immediately available rewards. Consistent with a domain-general view, an influential study found that the VS, vmPFC as well as the posterior cingulate cortex (PCC), tracked the discounted subjective value of future rewards (Kable & Glimcher, 2007). Subjective value is crucial; evidence suggests that the brain does not represent objective value of available options but takes into account individual preferences and contextual information to calculate the end value of an option to the organism. Thus, if one values an option less, such as a temporally discounted reward, activity in these regions will be less than an equivalent reward that is immediately available. Moreover, an individual with a steep discounting function (i.e. an “impulsive” individual) will show less activity in these regions for a delayed reward than an

individual that discounts less steeply. This is consistent with a domain-general view of this valuation network, in which subjective value is represented in a variety of domains. For example, stimuli that are proximal to the self, and higher in subjective value, engage vmPFC to a greater extent than do distal stimuli (Tamir & Mitchell, in press). Thus, the value that is computed by the valuation network for a potential reward determines the likelihood that that reward will be chosen.

Cognitive Control

In addition to systems representing incentive value of options, brain networks involved in resolving conflict and implementing strategies play a role in decision-making. In particular, regions of the brain involved in cognitive control, such as dorsolateral prefrontal cortex (DLPFC) and the anterior cingulate cortex (ACC) help resolve conflict between two options that are close in subjective value. A choice between two options which are valued similarly by the valuation network require additional top-down biasing in order to select a reward. This is consistent with findings that activity in DLPFC and ACC increase when the subjective value of an immediate reward and a delayed reward are very close. ACC activity also reflects increases in conflict-induced response times. In regards to the function of ACC signals, some propose that they serve to bias behavior towards less demanding and more efficient strategies (Peters and Buchel, 2011). This is consistent with a recent finding that valuation signals in ACC correlate with the degree of change in temporal discounting between two different experimental contents (Peters and Buchel, 2010).

In addition to conflict resolution, DLPFC seems to play an important role in biasing value signals in vmPFC to conform to higher-level goals. In a recent study, dieters made real

decisions about food consumption and rated food stimuli on their taste and health value. VmPFC tracked goal-value in all subjects; however, only subjects that exhibited self-control behaviorally (self-controllers) incorporated both health and taste value into this value signal. Moreover, when self-controllers exercised self-control, DLPFC activity increased and modulated the value signal in vmPFC via ventrolateral PFC (Hare, Camerer, & Rangel, 2009). Thus, it seems that the ability to modulate subjective value in vmPFC to incorporate higher-level goals depends on top-down modulation from DLPFC.

In regards to temporal discounting, this suggests that DLPFC should increase in activity when subjects successfully exercise self-control and modulate their value signal in vmPFC in order to select the future reward. Indeed, many have found that choosing the later choice engages DLPFC (McClure et al., 2004). Moreover, a recent study found that subjects were more likely to choose the immediate option in difficult trials when rTMS was used to disrupt processing in left lateral prefrontal cortex (LPFC) (Figner et al., 2010). Importantly, this effect was greatest when the two options were close in subjective value, suggesting LPFC plays a greater role in biasing vmPFC value signals when decisions are difficult. Importantly, disrupting LPFC only affected decisions made but not valuation of the same rewards. These findings are consistent with a domain-general computation of subjective value occurring in vmPFC, which can be modulated by DLPFC to raise the value of rewards that are difficult to choose (such as temporally distant offers).

Episodic Future Thought and Temporal Discounting

Of recent research interest has been the role of thinking about the future, or episodic future thought, in human's ability to delay gratification relative to other species. In

particular, some have suggested that the ability to envision the future to determine the potential value of a future option plays a role in the ability to choose a larger delayed reward when a smaller immediate award is available. The specific role that episodic future thought plays in reducing temporal discounting, however, is not well known.

Episodic future thought is the process of constructing a scene of the future using information from previous experiences, episodic memory, in order to make predictions about possibilities in one's future. Such "prospective" processes allow people to forecast and care about events that are not currently affecting them but may come into play later on. While the exact mechanisms and computations involved in these processes are still underspecified, specific brain regions seem to play a prominent role. These brain areas include the medial temporal lobe (MTL), which also plays a large role in episodic memory, the vmPFC and the PCC (Schacter & Addis, 2009; Schacter, Addis, & Buckner, 2007; 2008).

In particular, it is thought that the MTL and PCC allow construction of hypothetical events from episodic memories of previous events. This is supported by the finding that both of these areas also are active for memory retrieval tasks. In fact, one study directly compared elaboration of future and past episodes and found almost complete overlap in activation between these two regions (Addis, 2007). In addition, another study found that when participants were asked to imagine themselves in an unfamiliar setting, with no episodic memories from that context, the MTL and PCC exhibited relatively little activity (Szpunar, 2009). Despite the overwhelming similarity in brain activity between these two processes, there does seem to be some areas that are specifically activated for future thought. In particular, the anterior hippocampus was more engaged for future thought, suggesting this area is involved in the reconstruction of episodes. Moreover, anterior areas

of vmPFC have been found to activate for envisioning future emotional events.

Interestingly, this area shows greater activity for far future events compared to near future events. This adds confusion about the role of vmPFC, given that far future events have lower subjective value and would be expected to show less activity in vmPFC valuation regions (D'Armenteau, Xue, Lu, Van der Linden, & Bechara, 2008).

Given that intertemporal choice necessitates that subjects consider a future option, it is logical to assume that episodic future thought might play a role in truly evaluating the future option. For example, the reduction in temporal discounting with age in adolescence has been associated with increased future orientation, not impulse control (Steinberg et al, 2007). Furthermore, the link between episodic future thought and intertemporal choice is obviated by the consistent activation of the medial temporal lobe in intertemporal choice tasks. Additionally, damage to the hippocampus increases temporal discounting in rats (Cheung & Cardinal, 2005). Given the clear theoretical and neural overlap between these two processes, there has been a recent surge of interest in investigating their interaction.

One recent study looked at the modulatory effect that MTL-mediated future thought has on intertemporal choice (Peters & Büchel, 2010). In this study, the investigators conducted a pre-scan interview to determine future events that subjects had planned. The subjects then completed a modified temporal discounting task that presented cues referring to the future events subjects from the interview. For example, if a subject said they had an upcoming vacation in Paris in two months, a reminder cue (e.g. "vacation paris") would be presented to them in a trial when they were deciding between an immediate reward and a reward in two months. Interestingly, neural valuation signals in the ACC and functional coupling of the ACC with the hippocampus and amygdala predicted

the extent to which discounting was modulated by future thought. In addition, an imagery score was calculated for each subject from imagery intensity and frequency scores they gave to their future thought episodes. A robust regression found that subjects with higher imagery scores discounted less. The findings from this study suggest that MTL mediated future thought serve to increase the valuation signal which future rewards elicit via episodic imagery, in turn reducing temporal discounting.

A more recent study asked subjects to imagine a specific event of spending money. Participants were given a delay period, a monetary amount and a specific contextual cue (e.g., \$35 in 180 days at a pub) and asked to either imagine spending the money or merely estimate what the money could buy. Immediately afterwards, participants were asked to make a binary choice between that future amount and a smaller reward available immediately. Imagining, but not estimating, reduced temporal discounting. Additionally, activity in medial rostral prefrontal cortex (mrPFC) predicted future-oriented choices on a trial-by-trial basis. Increased mrPFC-Hippocampus coupling resulted in a greater reduction in temporal discounting. The authors suggest that mrPFC uses information from the hippocampus to represent the undiscounted utility of envisioned events. Experiencing the delay reward through episodic future thought biases one toward farsighted decisions (Benoit, S. J. Gilbert, & Burgess, 2011).

The results from the previous two studies provide a host of exciting possibilities but also raise questions regarding the specific roles regions involved in both future thought and intertemporal choice are playing. In particular, the previous two studies found different areas that were postulated to represent the value obtained from the hippocampus (ACC and mrPFC). Moreover, it is not clear if the process by which the future option is

biased with future thought is by the specific increase of the appetitive value of the future option (as represented in vmPFC), or a more general effect of thinking about the future. Thinking about the future could increase the participant's orientation to the future on that trial, and in turn increase their propensity to choose the delayed option. Less interesting but also problematic is that simply by engaging in imagery, the appetitive value of the present option could be reduced; since the "estimate" condition in the aforementioned study does not engage imagery, no proper condition has been included to control for that possibility. Finally, a difficult problem to avoid, demand characteristics, could be present in the previous two studies. In both studies, when episodic future thought was induced, it was on a specific choice that they were facing; it is possible demand characteristics could have played a role in the temporal discounting reduction given that the connection between episodic future thought and the decision-making trial was not occluded.

Present Experiment Overview

The present experiment will help elucidate the process that mediates how temporal discounting may be reduced by invoking episodes of future thought. In particular, three changes were made from the previous studies. First, in addition to having participants think about the future, we will also ask them to think about the past. Given the overwhelming overlap in the neural systems recruited by episodic future thought and episodic past thought (Addis, Wong, & Schacter, 2007; Szpunar, Watson, & McDermott, 2007) it is possible that a common processes to both future and past thought is driving the reduction in temporal discounting. In particular, some have suggested that the ability to escape from the present and be oriented to time in general, not just to future, might underlie the ability to make patient choices (Steinberg, 2007). This is consistent with the

idea that thinking about the past informs decisions made in the present. Moreover, having a past thought control condition will provide a baseline for both behavioral and future neuroimaging analyses to isolate any unique contribution of future thought.

The second change we introduce is to induce episodic thought via priming using a word-cue paradigm rather than by specifically asking individuals to think about a specific episodic future event when making their decision. The motivation for this manipulation is twofold. First, by having participants thinking about specific episodes (either in the past or future) that is unrelated to the specific choices they will be making, we will be testing the hypothesis that the reduction in temporal discounting shown in the aforementioned studies is due to a general increase in temporal orientation rather than an increase of the appetitive value of the particular future option. In particular, Benoit (2011) suggested that thinking about the future option allowed the undiscounted value representation to be transferred from memory to valuation systems. This resulted in greater subjective value for the future choice, increasing the likelihood that it would be chosen. However, if, as we test, unrelated episodic temporal thought reduces temporal discounting, it would suggest that the reduction of TD by episodic future thought is more general and the underlying process is driven by “temporal orientation”. Second, by making thinking about a future (or past) episode unrelated to the subsequent choice that the participant will make, it is less likely that the participant is likely to make the future choice in an attempt to please the researcher or comply with what they believe is the task goal (i.e. demand characteristics). Thus, if an effect is found, it is more likely to be from a true change in preferences that is mediated by episodic thought rather than by demand characteristics, as is possible in the prior study by Benoit et al. (2011).

A final change to the design that will be made is to include an “imagery” baseline. In particular, it is hypothesized that the reduction of temporal discounting by episodic future thought is driven by the use of mental imagery. However, no studies have compared episodic future thought to a condition, which includes mental imagery but does not include episodic thought. By using mental imagery as a baseline, we can confirm that the observed reduction in TD is not due to a general byproduct of mental imagery, but to the use of mental imagery by episodic future thought processes.

In summary, the present study will further investigate state changes of TD by episodic future thought by 1) adding an episodic past thought condition 2) adding an imagery control condition and 3) having episodic imagery be unrelated to the decision-making trial. This will 1) test the idea that TD is reduced by a more general “temporal orientation,” 2) provide addition control to which we can compare the reduction of TD by episodic future thought and 3) test the hypothesis that episodic past thought can also reduce TD.

Methods

Participants

In total, data from 44 subjects are included in the present study. Subjects provided informed written consent and the study was approved by the Institutional Review Board. 10 participants were excluded from the study because their discount functions were classified as nonsystematic. i.e., they either did not discount by at least 10% of the immediate reward even at the longest delay (indicating that no discounting occurred), at least one indifference point was greater than the preceding indifference point by a value of more than 20% of the immediate reward indicating inconsistent preferences (Johnson & Bickel, 2008). Prior studies have shown similar rates of exclusion (Kable & Glimcher, 2007; Peters & Büchel, 2010)

Imagination and Decision-Making Task

Thirty past, future and imagery control trials were presented for a total of 90 trials. Trials were pseudorandomized such that trials of the same type did not occur more than twice in a row. Each trial was 14s in duration and consisted of an episodic construction and elaboration phase followed by an intertemporal choice phase.

The *episodic construction and elaboration phase* consisted of a modified Crovitz cueing procedure (Crovitz & Schiffman, 1974; Addis, Wong, & Schacter, 2007) in which participants used a word cue to imagine one of three things: a) a past event, b) a plausible future event, or c) performed a control imagery condition. For the duration of this phase, a cue slide was presented which consisted of the task condition (past, future or imagery control) and a cue word. In the past condition, participants used the cue to think of a memory that had happened to them in the last two years, whereas in the future condition

they used the cue to think of a plausible event that could happen to them in the next two years. The event did not have to be strictly related to the presented cue and participants were encouraged to use the cue to help them think of a specific event (for example, for the cue “ski” and the condition “past”, the participant need not be a skier; they could think of the last time they heard about somebody going skiing or it could remind them of a movie they saw in which someone skied). Participants were instructed to press a button when they “found” a specific event to imagine and to use the remaining time to elaborate on the episode. This was done to encourage participants to participate in the task and have a measure to compare the similarity between the conditions. They were encouraged to elaborate on the details of the episode including visual imagery for the remainder of the time.

In the imagery control condition, participants used the cue to generate in their minds two objects – one smaller and one larger - than the cue object. They were instructed to press a button once they had generated the two objects and use the rest of the time to elaborate on the perceptual details of the objects they were imagining. This condition was designed to engage participants in visual imagery while eliminating the episodic and temporal aspects of the “past” and “future” conditions (Addis et al., 2007). In all conditions, the reaction time to generate the targets of imagery was recorded and the cues remained on the screen for the remainder of the trial.

During the *intertemporal choice phase*, participants performed a trial from a standard delay discounting procedure. In each trial, two choices were presented for four seconds – an immediately available reward of \$10 dollars and a reward available at a variable delay that was higher in value. Participants were then given two seconds to choose

either the immediate or delayed reward. In total, there were 30 trials that were used for each of the 3 conditions. These trials consisted of five delays (5, 10, 21, 42, and 120 days) and six reward amounts for the future option (ranging from \$11-27). The specific delays and reward values used were chosen on the basis of pilot work to determine ranges that would appropriately capture the discounting function of participants. Participants were informed that as (partial) payment for their participation one of their choices they selected would be randomly chosen and that they would receive the selected amount in the form of an Amazon.com gift certificate at the specified delay. For example, if the participant chose \$20 in 42 days instead of \$10 now, and that choice was randomly selected for their payment, that individuals would receive a gift certificate via email in 42 days in the amount of \$20. A two second interstimulus interval separated the end of the intertemporal choice phase and the beginning of the next trial.

Phenomenological Ratings

Following the “imagination and decision-making” task , participants were asked to rate phenomenological attributes of imagery from the first phase. All attributes were rated using a 6 point scale. Participants were shown each word cue and the condition in which it occurred and asked to rate imagery vividness (no image at all ... perfectly clear and vivid), emotionality (detachment ... highly emotional) and personal significance (insignificant ... very personally significant) of the imagery. For cues occurring for the “past” and “future” conditions, they were also asked how far in the past/future the episode they imagined was using a 5 point scale. Finally at the end of experiment, participants were asked if they were aware that the intent of the experiment was to influence their intertemporal decisions using episodic imagery.

Stimuli

Cue words for the episodic construction and elaboration phase were selected from the MRC Psycholinguistics Database (<http://www.psy.uwa.edu.au/mrcdatabase>). Words were selected such that they were high on concreteness (mean = 585 out of 700), imaginability (mean = 595 out of 700), meaningfulness (mean = 528 out of 700), and familiarity (mean = 581 out of 700). The stimuli were split into three lists of 30 words and the lists were matched on all four ratings and number of letters. Usage of the separate lists in the three conditions was counterbalanced across subjects.

Data Analysis

Individual's choice behaviors was analyzed using R Project for Statistical Computing. Each subject's indifference points were calculated at each delay and fit to individualized discounting curves for each condition separately. For each delay, subjects' choices were binarized as either choosing the delayed choice (1) or not (0). Then, a logistic function was fit on the choice values and the delayed reward values. Using the parameters from the fit, the later value at which participants were indifferent (or had a 0.5 chance probability of choosing either option) was determined. Due to the assumptions of logistic functions, certain values had to be assumed when the subject's choices violated these assumptions. In particular, when subjects made only one type of response for a delay, the logistic function failed to fit and the indifference point was assumed to be just outside of the range of values presented (30.5 in the case of all "now" responses and 10.5 in the case of all "later" responses). These values were the closest possible indifference points to half a dollar to the possible estimates that could be made using the delayed values shown. Discounted value

(DV) was calculated for each delay using the indifference points (DV=\$10/indifference point).

Next, the following hyperbolic discounting function was fit to the DVs:

$DV = 1/(1 + k \cdot D)$, where D is the delay length in days and k is the unknown discounting parameter. Nonlinear least squares were used to obtain an estimate of the k parameter. The hyperbolic function used is a standard method for modeling temporal discounting functions. As the resulting distribution of k parameters failed the Shapiro-Wilk test for normality ($W = 0.7037$, $p < .001$), k values were log transformed in order to conform to assumptions of the GL. Prior studies have made similar transformations (Peters & Büchel, 2010).

In order to estimate the effects of imagery condition (past, future, size) on temporal discounting (k), we fit a linear mixed effects model using *lme* from the nlme package for R. In particular, we entered imagery control condition (past, future, or imagery control) as a predictor and log (k) as the response variable. We treated condition as a fixed effect and subject as a random effect. The resulting analysis is equivalent to a repeated measures ANOVA. We then used contrast codes to test for various combinations of group relationships adhoc (i.e. Future v Past, Past vs Future & Imagery Control).

We also investigated the relationship of phenomenological ratings given to specific imagery episodes in order to compare the three conditions and determine which attributes best predicted intertemporal choice. To do this, we employed a linear mixed effects model with restricted maximum likelihood (REML) estimation using the *lmer* function from the lme4 package for R. First, we investigated the relationship of emotionality, imagery intensity and self-relevance to choice behavior by regressing the three predictors on later

responses across the entire dataset. The three item predictors were modeled as fixed effects because they showed low standard errors when modeled as random effects. Subject number and cue word were included in the model as random effects. In order to include time ratings into the model, we excluded the imagery control (with no temporal ratings), and added time into the model, separately.

Results

Decision-making phase

K values obtained from curve fitting to individual's DVs ranged from 0.0016 to 0.1148, suggesting there was a wide range of individual differences in temporal discounting in our sample. K values were highly correlated with average percentage of later responses in each condition (Pearson's $r = -0.86$, $p < .001$), suggesting that k values were representative of choice behavior.

In order to investigate the effect of mental imagery on intertemporal choice, we regressed condition type on the k discounting parameters, revealing of an effect of condition ($t_{32} = 2.8$, $p < .05$; Table 1). By comparing conditions, it was revealed that the effects were driven by the past condition, such that participants showed less temporal discounting on decision-making trials following episodic past thought compared to the other two conditions ($F = 4.81$, $p < .05$). These findings suggest that thinking about the past reduces temporal discounting.

Condition	Mean	Median	Mean Log
Imagery Control	0.0211	0.0131	-4.252
Past	0.0209	0.0124	-4.362
Future	0.0221	0.0132	-4.277

Table 1. Descriptive statistics for k across conditions. Given the skewness of k, median and mean of the log of k are reported.

Episodic construction and elaboration phase

Reaction times (RTs) indicating that subjects found a target for imagery differed between the episodic conditions and the imagery control ($t_{32} = 11.47$). This suggests that the two episodic thought conditions were matched but the imagery control may have been more difficult or time consuming.

Phenomenological ratings support that the imagery task was performed as intended, as ratings of visual imagery intensity, emotionality and self-relevance for the episodic conditions were greater than for the imagery control condition ($t_{32}=8.06$, $t_{32}=4.30$, $t_{32}=8.50$, Table 2). This supports that the task was completed as intended, since episodic thought would be predicted to be more emotional, self-relevant and visually vivid than abstract visual imagery. However, imagery intensity was also greater for past compared to future ($t_{25}=4.68$), suggesting the two episodic conditions may not be completely balanced in regards to imagery intensity. Finally, no differences were found between past and the imagery control in temporal distance from the present, emotionality and self-relevance supporting that the two episodic conditions were mostly well balanced

Condition	Intensity	Emotionality	Self-Relevance	Time	RT (msec)
Imagery Control	3.15	1.77	1.70	NA	3093
Past	3.74	2.82	2.76	3.75	2424
Future	3.32	2.55	2.60	3.79	2408

Table 2. Phenomenological ratings and reaction time for the episodic construction and elaboration phase. All phenomenological ratings were greater for episodic conditions compared to the imagery control condition. Differences between the episodic conditions were only found for intensity ratings.

Relationship between phenomenological ratings and choice behavior

In order to investigate the question of what attributes of mental imagery might influence temporal discounting, we regressed the phenomenological ratings for each trial on the reward choice made. None of the phenomenological ratings significantly predicted intertemporal choice. These findings are surprising because prior studies have found imagery intensity to correlate with choice behavior. Furthermore, an interaction between emotionality and episodic condition (future vs past) approached significance ($p=0.06$), such that emotionality was more related to later choices for past compared to future. The fact that the past thought condition was a novel feature of this study may explain why this relationship has not been previously found. In addition, there was a near significant interaction between self-relevance and episodic condition, such that the relationship between self-relevance and later choices is greater for future compared to past ($p=.06$). This finding is of interest because, again, previous studies have found imagery intensity to be the most predictive of intertemporal choice, not self-relevance. These differences also hint at how these episodic processes may differ in their interaction with decision-making.

In an attempt to replicate the existing finding that imagery predicts discounting, we conducted a more liberal analysis that excluded subject as a random effect. With this approach, intensity is the most predictive of choice ($z=3.18$, $p<.001$) such that more vividly intense imagery predicts later choices. These findings are in concordance with the existing literature and suggest that this effect is only found when within-subject correlations are not appropriately modeled. In order to confirm this conclusion, we regressed the average ratings for each condition, for each subject, on the discounting parameter k . This group-level analysis also found that imagery predicts discounting. This suggests that imagery intensity can predict discounting across subjects, but not within subjects. In other words, there are individual differences between subjects such that those that rate their imagery as higher discount less, but within subjects, trials that are rated more highly on imagery are not more likely to be later choices.

Discussion

The results of the present experiment provide evidence for an effect of episodic past thought on subsequent intertemporal choice such that thinking about the past prior to making intertemporal choices reduces temporal discounting (TD). Moreover, there is evidence that the effect of episodic memory on temporal discounting is greater than the effect of episodic future thought on TD. However, we did not find evidence that episodic future thought reduces TD.

Episodic Memory and Temporal Discounting

As demonstrated by the difference in temporal discounting between the imagery control condition and the past thought condition, thinking about past episodic events prior

to making an intertemporal choice reduces temporal discounting. This finding is very interesting in particular in relation to the previously established finding that episodic future thought reduces TD. In some ways, this finding shouldn't be surprising given that episodic past and future thought share many common processes such as constructivism, visual imagery, a removal from the present moment, and a temporal component. Thus, it is quite likely that a common episodic process is responsible for the reduction of temporal discounting. The present findings suggest that further research should be devoted to disentangling the commonalities and differences of future and past thought and how they influence temporal discounting.

Moreover, the current literature on state modulation of temporal discounting has largely focused on the aforementioned effect of future thought on TD. However, the present findings suggest that further research needs to be conducted on the effects of episodic memory on temporal discounting.. Such a relationship would be consistent with the idea that thinking about the past involves reflecting on past consequences and may inform present decision-making. Moreover, thinking about the past may allow you to escape the present moment more vividly than thinking about the future. The finding that participants rated imagery intensity as higher in the past compared to future supports this possibility. The magnitude of these effects should be further studied in order to make further conclusions.

Episodic Future Thought and the Imagery Control

The present experiment failed to find a significant difference between the imagery control and the episodic future thought condition. There are a few interpretations of these results. First, it could be that the control was not sufficiently neutral and either through

similar or different mechanisms also reduced TD. There is some evidence that this may be the case because the reaction time was greater for this condition than the episodic conditions. It may be that the increased effort or time on task spent creating targets of imagery reduced TD in the control and masked any additional decrease by episodic future thought when using this imagery control as the baseline. If this is true, matching the time on task for all three conditions should reveal an effect of future thought on TD. Another possibility is that the imagery control reduced TD through imagery mechanisms common to the other two conditions. This cannot be ruled out, as previous experiments have not used an imagery control such as this. In particular, Benoit et al (2011) used an “estimate” control that did not have an imagery component and Peters and Buchel (2011) simply used standard intertemporal choice trials as their baseline. In order to resolve these issues, future work should compare different control conditions versus the episodic conditions. It would be useful to also compare a non-imagery control with imagery controls to investigate the role of pure imagery in reducing TD.

Furthermore, it is possible that other changes in the paradigm led to the lack of an effect of episodic future thought on TD. In particular, the present experiment relied on priming from the episodic construction and imagery phase to be strong enough to affect decision-making trials. This is opposed to Peters and Buchel (2011), where a cue word representing a future event was displayed on the screen during the decision-making trial. One possibility for future research is to adapt the Peters and Buchel paradigm with an added past condition and compare their effects on TD. If past also reduced TD in that experiment, it would suggest that the present methodology was simply less effective, but the fundamental mechanisms are similar. If the pattern of results were different, it would

suggest that the two methodologies are fundamentally different in the mechanism by which they influence decision-making.

Episodic Future Thought & Intertemporal Choice Mechanisms

A goal of the present experiment was to test the hypothesis that the reduction in TD by episodic future thought was due a general “temporal orientation”. A current view in the literature is that the mechanism by which TD is reduced is that a specific value representation is activated by future thought and transferred from memory systems to valuation systems. In the present experiment, participants engaged in future thought unrelated to specific later choice present; thus if future thought reduced TD, it would suggest that this is accomplished by a general “time orientation” not a specific value representation. An additional interpretation of the present result that episodic future thought did not reduce TD is that the mechanisms underlying previously found reduction of TD by future thought are indeed dependent on a specific value representation. In other words, the present methodology in which participants imagined a future event unrelated to the delayed reward did not reduce their TD because their imagery did not activate the *specific* value representation related to the delayed option. If this is the case, it would be very interesting because despite the similarities between episodic past and future thought, it seems that past thought does not require a specific value representation in order to reduce TD while future thought does. Further research should explore this issue. Presently we are limited because subjects rated past imagery and emotionality as being greater. Thus it is possible that those differences led to the differences between the two episodic conditions. Future studies should attempt to both increase their power to find differences

by strengthening their episodic thought manipulations and further matching the two conditions.

Awareness

Finally, another concern regarding the present experiment is that the methodology may have been too transparent, and subjects modified their responses when they became aware of the nature of the experiment. This is suggested by the finding that 56% of participants reported being aware of the intent of the manipulation. Unfortunately, we do not have sufficient subjects to investigate differences between aware and unaware subjects but this may suggest that a different paradigm may better mask the intent of the priming from subjects. Moreover, the priming effects may have a longer duration and may require longer blocks of episodic thought in order to have a larger effect on decision-making. A follow-up study to resolve these issues could be done by modifying the experiment to be a between-subjects design. In particular, if participants performed a 20 minute imagery session followed by a block of decision-making trials, it would obscure the manipulation and ensure strong priming.

Relationship between imagery intensity and discounting

Prior studies in the literature have found that imagery intensity is a key attribute of episodic thought that reduces temporal discounting (Peters & Büchel, 2010). However, by employing mixed effects models that require within-subject correlations, we found that intensity does not predict later choices at the subject level. However, at the group level, imagery intensity is predictive of overall discounting at between subjects. These findings are important for theories about the nature of these processes. In particular, it suggests that imagery capacities are likely to differ across subjects, such that those that can better

imagine the future or past show overall lower levels of discounting. However, this is more akin to a trait difference than a state-difference. In other words, a more intense imagery episode is not more likely to reduce TD transiently. In the current literature, such differentiations have not been clearly made and the present results suggest that future studies should be more careful about within versus between subjects predictors of temporal discounting.

In conclusion, the present experiment suggests that episodic past thought may have a greater effect in reduction of temporal discounting than the focus of the current literature, episodic future thought. However, the present study also highlights some differences between the two processes and opens some questions about how their mechanisms may differ. In particular, the question of whether a specific value representation is required for future but not past episodic thought in order to reduce TD needs to be further investigated. Episodic thought has the ability to remove us from the here and now, allowing us to reflect on our actions and decisions, and it may be these processes that can reduce temporal discounting.

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