Dissociable Neural Contributions To Prospection During Decisions About The Future

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Dissociable Neural Contributions To Prospection During Decisions About The Future

Abstract
Humans often make decisions that involve tradeoffs between immediate and delayed consequences, and tend to devalue or discount future outcomes. This phenomenon, known as delay discounting, has several real-world implications. A high discounter, indicating more impulsive behavior, is more likely to engage in risky behavior such as smoking or gambling, while a low discounter, exhibiting more patient behavior, is more likely to attain better educational and financial outcomes. Recent studies demonstrate that under certain conditions, imagining the future reduces discounting. The goal of this thesis is to examine the cognitive role and neural basis of imagination during intertemporal choice, and investigate the mechanisms by which imagination influences decision-making. Chapter 2 examines how specific components of imagination modulate activity in specific nodes of the default mode network. We find that two components of imagination, construction and evaluation, distinctly activate the dorsal and ventral nodes of the default mode network, demonstrating separate modifiability and indicating a role for multiple processes underlying imagination. Chapter 3 extends this finding by examining activity in these nodes while participants are completing a choice task. Since tangibility and value are often confounded in intertemporal choice, we used our neural markers of construction and evaluation from Chapter 2 to disentangle these distinct components during choice. Though we find that activity in evaluative regions increases when individuals choose a delayed option, we also find greater activity in constructive regions when individuals choose a delayed outcome, indicating that chosen options are perhaps imagined more vividly than unchosen ones. Further, greater activity in constructive regions seems to be driven by high discounters, suggesting that higher discounters rely on vividness to a greater extent during choice than lower discounters. We extend this finding in Chapter 4 by investigating the effects of behavioral interventions of the constructive component on delay discounting. Surprisingly, we find that being a better visualizer is correlated with steeper discounting, and long-term training in visualization of personal future goals leads to greater impulsive behavior. Together, these findings advance our understanding of how specific imagination processes influence decision-making through differential neural activity, laying the groundwork for implementing targeted, personally-tailored future interventions to reduce risky behavior.

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DISSOCIABLE NEURAL CONTRIBUTIONS TO PROSPECTION DURING DECISIONS ABOUT THE FUTURE

Trishala Parthasarathi

A DISSERTATION

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CHAPTER 1 - Introduction

Delay discounting

Measurement and meaning of discount rates

Individuals often make decisions in their daily lives involving a tradeoff between immediate and delayed consequences. For example, people might choose between eating immediately appetizing but unhealthy food or eating healthier; between spending money from a recent paycheck or saving for retirement; or between the short-term pain of withdrawal and the long-term rewards of quitting smoking. Such tradeoffs are called intertemporal choices, and when facing such tradeoffs, people tend to devalue or discount long-term rewards. The extent to which an individual rejects large rewards in the future to obtain smaller rewards immediately is known as delay discounting (Kable & Glimcher, 2007). Humans and animals frequently discount the delayed consequences of their actions (Chung & Hernstein, 1967; Rachlin et al., 1991; Frederick, 2003; Mazur, 1984).

A task often used to measure delay discounting requires participants to choose between receiving a smaller monetary reward immediately or receiving a larger monetary reward sometime in the future (Kirby and Maraković, 1995). The primary behavioral outcome of a discounting task is the subject’s discount rate. Discount rates are used as a measure of how much the subjective value of a delayed reward decreases as a function of delay. They are estimated by fitting a logistic regression that assumes a person’s decisions are a stochastic function of the difference in subjective value between the two options. Subjective value (SV) is assumed to be a hyperbolic function of the reward amount (A) and delay (D), such that SV = A/(1+kD) where k is the participant’s discount rate. Larger k values indicate a greater degree of discounting future rewards, suggestive of impulsive behavior (Kable & Glimcher, 2007). Participants with lower discount rates, on the other hand, are more willing to wait for the delayed reward, suggestive of patient behavior. Discount rates have been shown to be very stable over
weeks (Senecal et al., 2012), months (Ohmura et al., 2006), and years (Kirby, 2009) in the absence of any manipulations.

**Individual differences in discounting**

While stable within individuals, the extent to which a delayed reward is discounted in this task varies greatly between subjects (Kable & Glimcher, 2007; Frederick, 2002). Critically, this variability in the laboratory is associated with variability in real-world discounting behavior. Individuals that frequently choose immediate monetary rewards are more likely to engage in risky behavior such as smoking, drug use, heavy drinking, and pathological gambling (Madden & Bickel, 2010; MacKillop et al., 2011; Petry et al., 2001, Audrain-McGovern et al., 2004, Kirby et al., 1999), while those that wait for a greater long-term payoff have better educational and financial outcomes (Shamosh & Gray, 2008; Becker et al., 2012). In addition, high discount rates precede risky behavior in adolescence and predict relapse (Perry & Carroll, 2008).

While there is great variability in individuals’ discounting behaviors, what accounts for these individual differences is relatively unknown. There have been some studies examining self-report measures and discount rates, but no single definitive measure has been found to explain the source of individual differences. For example, discount rates are negatively related to measures of intelligence, including IQ, education level, and college GPA (Shamosh & Gray, 2008; Kirby et al., 2005; Burks et al., 2009). Additionally, it has been reported that extroverted individuals are higher discounters (Hirsh et al., 2010, Hirsh et al., 2008, Ostaszewski, 1996), though not all studies find this (Manning et al., 2014; Becker et al., 2012), and reported associations may be confounded by other variables such as cognitive ability (Hirsh et al., 2008) or levels of positive mood (Hirsh et al., 2010). One potential source of inter-individual differences that has not been explored is variability in how an individual mentally represents the outcome. Chapter 3 will examine the relationship between individual differences in discounting behavior and variability in brain activity associated with imagination while Chapter 4 will investigate the relationship between variability in imagining the future and choice behavior.
Neural components of discounting

In discounting studies, the ventral striatum (VS), posterior cingulate cortex (PCC), and ventromedial prefrontal cortex (vmPFC) track the subjective value of delayed rewards (Kable & Glimcher, 2007; Bartra et al., 2013). In these studies, participants were asked to choose between a smaller reward available immediately and a larger reward available in the future. In order to examine the effects of subjective value, the smaller immediate reward was fixed while the larger delayed reward varied from trial to trial so that only one value was varied, and the participant’s discount function was used to calculate the subjective value of the varying delayed reward. Across trials, activity in the VS, vmPFC, and PCC significantly correlated with the subjective value of the larger later option. Activity in these regions increases as the magnitude of the delayed reward increases, and activity decreases as the time to receipt of the delayed reward increases. In addition, for high discounters there is greater activity in these regions for immediate compared to delayed rewards (Cooper et al., 2013).

Interventions to reduce discounting

Recent studies investigated the relationship between imagining the future and delay discounting, and suggested that in particular task contexts, future thinking reduced the rate of discounting, leading to more patient, future-minded behavior (Peters & Buchel, 2010; Benoit et al., 2011). Imagining specific events of spending money in the future biased decisions toward choices associated with a greater payoff. Envisioning possible future scenarios that are unrelated to spending money also motivated decisions in the present that can be advantageous in the future. In the Peters & Buchel study, subjects made choices between a fixed immediate option and a larger, delayed option. In the episodic condition, the choice was paired with an a subject-specific episodic cue indicating an event planned on the day a delayed reward would be delivered, while choices in the control condition only presented the amount and delay (Peters & Buchel, 2010). Results revealed that self-reported vivid imagery during the episodic condition predicted the extent to which subjects changed their preferences for the delayed option, such that
individuals with greater imagery scores were more likely to exhibit reduced discount rates in the episodic condition (Peters & Buchel, 2010). Even when the possible future scenario was not linked to the day the delayed reward will be received in other studies, imagining future scenarios still reduced discounting (Liu et al., 2013, Cheng et al., 2012).

Neural evidence also demonstrates a link between imagination and discounting. There is greater vmPFC activity when making judgments of oneself in the present compared to the future, and this effect is larger in high discounters compared to low discounters (Ersner-Hershfield et al., 2009; Mitchell et al., 2011). Additionally, previously published data from our lab indicate a relationship between imagining the future and discount rates (Cooper et al., 2013). Participants were asked to judge the delay between two time intervals ranging from 14 – 365 days in the scanner. In a second scanning session separated by an average of 10 days, participants completed the temporal discounting task where the delays were identical to those judged in the first task. The neural sensitivity to delay was estimated to obtain a measure of how activity in vmPFC and VS changes as a function of delay in the temporal judgments task. This sensitivity was then related to individual discount rates. Results revealed that participants who were lower discounters exhibited greater changes in delay sensitivity, such that there was greater activity for the far future compared to the near future. The opposite effect was seen in high discounters. Thus, lower discounters had greater vmPFC activation when judging the longer delays, and higher discounters had greater vmPFC activation when judging the shorter delays (Cooper et al., 2013). In neuroimaging studies where experimenters used imagination to reduce discounting, the areas recruited during imagination overlap with those recruited during valuation. Peters & Buchel found greater functional coupling between prefrontal areas, including the anterior cingulate cortex, and the hippocampus and amygdala, predicted the degree to which future thinking modulated discounting, suggesting that scene construction and emotions may be involved in processing future rewards (Peters & Buchel, 2010). This thesis will further investigate the
processes underlying imagination to understand what specific components are involved in mediating the effect of imagining the future on discounting.

**Imagination**

*Behavioral components of imagination*

Humans frequently engage in mental time travel, that is, re-experiencing events that have previously occurred or imagining future events. Imagining the future can aid planning and decision-making and help one act flexibly in the present. From examining studies that investigate episodic future thinking or prospection (Atance & O'Neill, 2001; Boyer, 2008; Schacter, 2007), two main components of imagination seem to be construction and evaluation. Construction refers to combining elements of the past to create a novel future event (Addis et al., 2007; Schacter et al. 2007; Hassabis et al., 2007; Hassabis & Maguire, 2007). Scene construction can also map onto the vividness of an imagined future event, referring to the amount of detail or concreteness. Additionally, individuals with higher capacity of visual imagery experience greater visual and sensory details for the past and future (D’Argembeau et al., 2008). The evaluative process of imagination refers to whether the imagined event is judged as positive or negative. This can be mapped onto the valence of an imagined future event. In general, representations of positive future scenarios are associated with a greater feeling of pre-experiencing than representations of negative scenarios (D’Argembeau et al., 2004). Neural evidence provides further insights into the structure of imagination.

*Neural components of imagination*

Because imagination can be difficult to examine using behavioral alone, neuroimaging is required to look at its underlying architecture. Studies that investigated imagining future scenarios have typically found activation in regions of the default mode network (DMN) (Botzung et al., 2008, Buckner et al., 2008, Okuda et al., 2003, Addis et al., 2007, Szpunar et al., 2007). The DMN is known to be activated at rest when participants are left undisturbed and generating spontaneous thought. Studies that collected imaging data during rest as an experimental control
fortuitously discovered that activity in specific brain regions increased during passive states as compared to during goal-directed tasks (Raichle et al., 2001, Buckner et al., 2008). These areas coincide with those seen when participants imagine the future, including regions in the medial temporal and parietal lobes such as the hippocampus and precuneus, as well as areas implicated in subjective value such as the vmPFC and PCC (Raichle et al., 2001, Raichle, 2015, Shulman et al., 1997, Greicius et al., 2004, Andrews-Hanna et al., 2007, Andrews-Hanna et al., 2010, Spreng et al., 2009). In the studies of imagination, participants were asked to generate a series of episodic cues prior to the scanner task. In the scanner, participants were given a period of time to construct an imagined future event based on a random presentation of cues generated previously. Results revealed increased activity in the vmPFC, PCC, and hippocampus when participants were asked to imagine an event compared to a control condition when no imagination took place (Sharot et al., 2007, Addis et al., 2007). The DMN is also engaged when people are involved in mental time travel during tasks with autobiographic recall, self-relevance, self-continuity or when thinking about someone else's perspective (Addis et al., 2007, Atance et al., 2001, Schacter et al., 2007).

Prior research indicates that different components of the DMN may be engaged during different components of imagination. Studies that examine scene construction reveal activity in the medial temporal areas, including hippocampus, parahippocampal gyrus, and retrosplenial cortex (Andrews-Hanna et al., 2007, Hassabis & Maguire, 2007; Hassabis et al., 2007). In imagination tasks with an evaluative component, activity is seen in the vmPFC (Sharot et al., 2007, D’Argembeau et al., 2008) when participants imagine positive scenarios relative to neural ones.

Andrews-Hanna et al., (2010) suggested a sub-division of the DMN into the medial temporal, core, and dorsomedial subsystems. The MTL subsystem includes the hippocampus, parahippocampal gyrus, retrosplenial cortex, vmPFC, and posterior parietal regions. The DMN core consists of the mPFC and PCC, while the dorsomedial subsystem consists of the
dorsomedial PFC and the temporoparietal junction (TPJ). Other groups have proposed similar DMN sub-divisions, such as dorsal and ventral DMN which are functionally similar to the DMN core and MTL subsystems respectively (Shirer et al., 2013).

However, studies have not simultaneously manipulated the constructive and evaluative components to determine whether, and if so how, imagination depends on separate neural networks for these processes. Chapter 2 will discuss how manipulating both these components of imagination reveals a double dissociation in distinct nodes of the DMN. We then examine how these dissociable subcomponents are differentially engaged during decision-making.

**Relationship between imagining the future and discounting**

Past research has revealed that behaviorally, imagining the future might be one way to potentially reduce the phenomenon of delay discounting. One interpretation of these findings is that imagination might increase the tangibility of future rewards since it is likely for outcomes in the far future to be less concrete and more intangible than outcomes in the near future (Peters & Buchel, 2010). Since tangibility has been linked to value, this also suggests that the future, intangible outcomes might be less valuable (Rick & Loewenstein, 2008). Therefore, imagination might also make the delayed outcome more valuable. Prior work has suggested that people discount delayed outcomes by the difficulty with which the specific outcome or reward is brought to mind. That is, more easily and vividly imagined future outcomes are discounted less than futures that are more difficult to imagine. In this case, imagining future scenarios could enhance future outcome availability and reduce discounting (Kurth-Nelson et al., 2012). Other studies that have examined this relationship found that imagining the actual consumption of reward, events around the time of future reward, or a future event in general all shift preferences towards the larger, delayed reward (Peters & Buchel, 2010; Daniel et al., 2013, Cheng et al., 2012), and suggest that the effect is due to the constructive processes of imagination.

Alternatively, perhaps evaluative processes are more important in mediating the effect of imagination on discounting. Neural activity in the prefrontal cortex and anterior cingulate are
involved in valuing future outcomes, perhaps by reflecting the emotional attributes of an imagined reward (Sharot et al., 2007, Benoit et al., 2011; Benoit, Szpunar & Schacter, 2014). Additionally, in the studies where imagining the future attenuated discount rates, the imagined future scenarios were always positive (Peters & Buchel 2010; Epstein et al., 2011, Benoit et al., 2011). Other behavioral evidence indicates negative imagination can in fact, increase discount rates (Liu et al., 2013). For example, Liu et al., 2013, found that participants were more likely to choose the immediate reward when imagining negative future events compared to no imagination; Lempert and Pizzagalli, 2010 demonstrated that when a stressor is present, imagining an event in the future increases preferences for immediate reward; Worthy et al., reported that engaging in emotionally aversive imagined events leads to greater preference for the immediate reward. Worthy and colleagues also demonstrated that high levels of worry is associated with more impulsive behavior (Worthy et al., 2014). Other studies showed that foreseeing a stressful, uncertain, or bleak future, led to shifting preferences towards the immediate reward (Bulley et al., 2016; Lempert et al., 2012), further suggesting a role for the evaluative circuit in mediating the effects of imagination on discounting.

Behavioral evidence examining abstract and concrete mindsets suggests that in contrast to the literature suggesting imagination leads to more patient behavior, enhancing constructive processes may, in fact, lead to a greater present-bias and thus greater impulsive behavior. Vivid imagination during an intertemporal choice can enhance vividness towards the present and future outcomes, and thus yield to further advantage for the already-vivid present. Past research demonstrates that visualizing in a concrete mindset compared to an abstract mindset raises present-bias and leads to greater impulsivity (Malkoc et al., 2010; Malkoc & Zauberman, 2006). Present-bias refers to the phenomenon that when people delay outcomes, they act as if they have higher discount rates for shorter periods. For example, people required an additional $50 to delay a $250 reward by three months, but an additional $100 to delay a $250 reward for one year (Thaler, 1981; Malkoc & Zauberman, 2006). However since not all intertemporal choices are the
same, Malkoc & Zauberman proposed that the framing of a decision will lead to different preferences and thus different degrees of present-bias. They therefore conducted a series of experiments manipulating whether participants were placed in an abstract or concrete mindset and looked at the influence on discount rates. They found higher discount rates when subjects had to concretely compare both options presented (i.e., two digital cameras, a particular person they know, or searching for concrete words in a word search puzzle) compared to comparing two abstract options (i.e. an analog and digital camera, all consumers, or searching for abstract words in a word search puzzle) (Malkoc et al., 2010). Additionally, in classic experiments on delayed gratification, manipulations that increased vividness of both the present and future outcomes increased impulsivity by reducing the ability to delay gratification (Mischel & Ebbesen, 1970). Abstract construal has also been linked with greater self-control, less present-bias and less discounting (Fujita et al., 2006, Malkoc & Zauberman, 2006).

Since there appear to be contradictory findings in the literature, Chapters 3 and 4 will investigate which one of these interpretations about the role of constructive processes provides the best explanation of how components of imagination influence choice. More specifically, Chapter 3 will examine how the constructive and evaluative neural components are involved in a delay discounting task, and Chapter 4 will investigate whether altering an individual’s overall tendency to vividly imagine the future, rather than manipulating the vividness of a single choice, can lead to changes in discounting behavior.

Research aims

The goal of this dissertation is to examine the components of imagination and investigate the underlying mechanism by which it influences valuation and choice during intertemporal decision making. The first section (Chapter 2) makes a significant contribution towards the division of the default mode network into constructive and evaluative sub-networks by simultaneously examining specific components of imagination. The next two sections (Chapters 3
and 4) provide an insight into how these components of imagination might be involved during decision-making, and seek to distinguish different possible explanations for how imagination might reduce discounting.

We begin, in Chapter 2, with an fMRI study of imagination. Despite numerous studies looking at imagining the future, few have attempted to study the underlying architecture of imagination. In this chapter, we independently manipulate the constructive and evaluative components of imagination and examine its effects on the DMN. We find a strong double dissociation, indicating that separate components of imagination do in fact modulate separate nodes of the DMN.

In Chapter 3, we look at how these separate nodes of the DMN, correspond to distinct aspects of imagination, are active during a discounting task. Tangibility and delay are often confounded in prior literature, as delayed outcomes are perceived to be both more intangible and less valuable (Rick & Loewenstein, 2008). Our neural data from Chapter 2 reveal that tangibility and positive evaluation are associated with distinct neural signatures, thus allowing us to separately examine tangibility (indexed by its neural signature) during chosen delayed outcomes. This aids in answering the question of whether there is a difference in vividness between delayed outcomes that are chosen versus delayed outcomes that are not chosen. We investigate this difference using region-of-interest analyses, comparing evaluative regions and constructive (vividness, tangibility) regions, when participants are making a choice, and relating activity in these regions to individual differences in discount rates. This builds on previous work examining concreteness of future outcomes in intertemporal choice, and allows us to answer the question of whether individuals represent chosen outcomes differently, and how this might be different for high versus low discounters. Do higher discounters represent delayed outcomes more or less vividly than low discounters? Our data provides evidence for the interpretation that relying on vividness as a cue for making a choice is more prevalent in high discounters.
Chapter 4 uses results from Chapter 3 to further investigate individual differences in imagination and discounting. We also examine how manipulating vividness might lead to behavioral changes in discounting, and whether these changes can persist long-term. We find a strong association between individual differences in visualization abilities and discount rates, such that individuals with greater visualization abilities are higher discounters. In addition, we find that enhancing participants’ visualization abilities, does in fact, lead to greater discounting, as suggested by our neural data. This provides further evidence for the theory that steeper discounters imagine outcomes in a vivid manner. Together, these studies suggest that the mechanism through which imagining the future reduces discounting, might not be by enhancing vividness, as previously proposed, but rather by enhancing another factor, perhaps greater positivity. These results have important implication for the design and interpretation of future intervention studies that seek to change risky behavior.
CHAPTER 2 – A double dissociation between the dorsal and ventral default mode network in the constructive versus evaluative functions of imagination

Parthasarathi T, Kable JW. Valence and vividness effects on the default mode network during imagination. *Under review at Psychological Science*

**Abstract**

Humans often imagine the future in order to make decisions. Previous work has suggested that imagination may depend on separate neural networks involved in the construction and evaluation of imagined future events, but strong evidence for this dissociation has been lacking. This study provides strong neural evidence for this dissociation by demonstrating that two components of the brain’s default mode network (DMN) uniquely and specifically respond to different aspects of imagination. The vividness of imagined events modulates the ventral DMN, but not the dorsal DMN, while the valence of imagined events modulates the dorsal DMN, but not the ventral DMN. This supports the dissociable engagement of these sub-networks in constructing and evaluating imagined future events.

**Introduction**

Humans often engage in “mental time travel”: remembering past events, imagining possible future events, and generally considering that which is not “here and now.” Imagining the future can aid planning and decision-making and help one act flexibly and advantageously in the present. The ability to consider different possible actions and accurately predict their potential consequences allows an individual to act so as to bring about positive outcomes and avoid negative outcomes. But what is the underlying cognitive architecture of imagination? Though imagination, like perception, can subjectively feel like a unitary experience, it may actually arise from the interaction of dissociable psychological processes. Here we investigate the hypothesis, inspired
by considering the function of imagination (Gilbert & Wilson, 2007), that imagination consists of at least two related yet distinct processes: a *constructive* process, by which a novel future event is mentally formed, often by combining specific aspects of past experience (Addis et al., 2007; Schacter et al., 2007; Hassabis & Maguire, 2007; Hassabis et al., 2007); and an *evaluative* process, by which the imagined event is judged as positive or negative (Gilbert & Wilson, 2007; Sharot et al., 2007; D’Argembeau & Van der Linden, 2004).

As imagination is fundamentally an internal, subjective activity, studying its architecture can be difficult with behavioral data alone, and therefore many studies have turned to brain imaging. These studies have often focused on the default mode network (DMN), as the ability to envision and evaluate future events is proposed to be a key function of the DMN (Addis et al., 2007; Sharot et al., 2007; D’Argembeau et al., 2008; Botzung et al., 2008; Buckner et al., 2008; Okuda et al., 2003; Fellows & Farah, 2007; Szpunar et al., 2007). The DMN includes the ventromedial prefrontal cortex (vmPFC) and posterior cingulate cortex (PCC), as well as regions in the medial temporal and parietal lobes, such as hippocampus and precuneus (Raichle et al., 2001; Raichle, 2015; Shulman et al., 1997; Greicius et al., 2004; Andrews-Hanna et al., 2007; Andrews-Hanna et al., 2010; Spreng et al., 2009; Bechara et al., 1994). The DMN has greater metabolic activity at “rest”, when participants are left undisturbed to generate spontaneous thought, than during different executive cognitive tasks (Raichle et al., 2001; Raichle, 2015; Shulman et al., 1997; Greicius et al., 2004; Andrews-Hanna et al., 2007; Andrews-Hanna et al., 2010; Spreng et al., 2009; Bechara et al., 1994; Fox et al., 2015). The DMN is one of the core networks reliably recovered from resting-state fMRI studies, showing correlated activity between different regions of the DMN (Greicius et al., 2004; Greicius et al., 2003; Damoiseaux et al., 2006). It is also a core network reliably activated when people engage in mental time travel in other ways, such as during tasks demanding autobiographic and social cognition, when people recall themselves in the past or think about someone else’s mental perspective (Addis et al.,
Past research suggests that constructive and evaluative processes may engage different components of the DMN. Studies of “scene construction,” when elements of the past are combined to create a novel potential future event, have revealed activity in the hippocampus, parahippocampal gyrus, and retrosplenial cortex (Greicius et al., 2004; Andrews-Hanna et al., 2007; Hassabis & Maguire, 2007; Hassabis et al., 2007). In contrast, activity in vmPFC is seen in tasks with an evaluative component. Studies of decision making have reliably found neural signals in vmPFC associated with the value of predicted future outcomes (Kable & Glimcher, 2007; Cooper et al., 2013), studies of emotion have reliably found neural signals in vmPFC related to affective valence (Sharot et al., 2007; D’Argembeau et al., 2008), and imagining positive events increases activity in vmPFC compared to imagining negative or control events (Sharot et al., 2007; D’Argembeau et al., 2008).

Andrews-Hanna and colleagues recently proposed a sub-division of the DMN (Andrews-Hanna et al., 2007; Andrews-Hanna et al., 2010). Using seed-based resting-state functional connectivity, they distinguished between a medial temporal lobe (MTL) subsystem, consisting of hippocampal, parahippocampal, retrosplenial, ventromedial prefrontal, and posterior parietal cortex, and a DMN core, consisting of medial prefrontal cortex and posterior cingulate cortex. Other groups have proposed a similar sub-division of the DMN using independent components analysis, between a dorsal DMN, which largely overlaps with the DMN core, and a ventral DMN, which largely overlaps with the MTL subsystem (Shirer et al., 2012).

Andrews-Hanna and colleagues also argued that these two sub-divisions served different constructive and evaluative functions, with the MTL subsystem (or ventral DMN) involved in the construction of mental scenes based on memory, and the DMN core (or dorsal DMN) involved in the affective evaluation of personal significance (Andrews-Hanna et al., 2007; Andrews-Hanna et al., 2010). However, the evidence supporting this conclusion was a single (as opposed to double)
dissociation in task activation: the MTL subsystem (or ventral DMN) was more active when imagining future than present events, while the DMN core (or dorsal DMN) was equally active in both conditions. Furthermore, other groups have found quite different results when contrasting present and future imagination, supporting a alternative subdivision of the DMN into anterior and posterior components (Xu et al., 2016). Other studies of resting-state functional connectivity (Uddin et al., 2008; Sestieri et al., 2011; Xu et al., 2016), meta-analytic co-activation (Laird et al., 2009; Laird et al., 2013), or dissociations during task fMRI have yielded yet additional proposals regarding DMN sub-divisions (Sestieri et al., 2011; Xu et al., 2016; Whitfield-Gabrieli et al., 2011; Leech et al., 2011; Bado et al., 2013). Thus, the evidence for the specific hypothesis that the DMN can be functionally divided into constructive and evaluative circuits remains uncertain.

We therefore constructed a stronger test of the hypothesis that the DMN consists of dissociable constructive and evaluative networks involved in future imagination. We rely on the logic of separate modifiability (Sternberg, 2001), which supports stronger inferences regarding dissociations in psychological or neural processes, by showing that two processes are differentially influenced by distinct factors within the same task. To modulate activity in brain regions engaged in constructive processes during imagination, we manipulate the vividness of imagined events, where vividness refers to the amount of detail or concreteness of the imagined event. To modulate activity in brain regions engaged in evaluative processes during imagination, we manipulate the valence of imagined events, where valence refers to the intensity of positive or negative emotions the imagined event invokes. If one component of the DMN is modulated by the vividness but not the valence of imagined events, while another component is modulated by valence but not vividness, this double dissociation would provide strong evidence for a functional division of the DMN associated with constructive versus evaluative processes.
Materials and methods

Subjects. Twenty-four participants (14 females, average age = 24.9 years, SD = 4.6 years) were recruited from the University of Pennsylvania and surrounding community. The sample size was determined to conform to typical sample sizes in neuroimaging studies. One additional participant was excluded for excessive head movement (shifts of at least 0.5 mm between >5% of adjacent time points). All participants were compensated for their time at $15 per hour, and provided consent prior to study procedures in accordance with the procedures of the Institutional Review Board of the University of Pennsylvania.

Imagination task. All participants completed an imagination task in the scanner. Participants were asked to imagine scenarios and then rate the imagined scenarios on vividness and valence on a 7-point Likert Scale (Figure 1).

Thirty-two scenarios were presented in each run and participants completed a total of 4 runs. The vividness and valence ratings were performed on a 7-point Likert Scale. To assess vividness, participants were asked “How vividly did you imagine this event” with anchors of “Vague with no details” to “Vividly clear.” To assess valence, participants were asked “How would you rate the valence of emotions in this event” with anchors of “Very Negative” to “Very Positive.”

Participants were given up to 5 seconds to read the cue, 15 seconds to imagine the scenario, up to 7 seconds to rate vividness, and up to 7 seconds to rate valence. The participant pressed a button indicating that the cue was read to start the imagination epoch. The imagination epoch was a fixed 15 seconds for all participants. Following imagination, participants were given up to 7 seconds to move a scale ranging from 1-7 to make their rating. If participants failed to submit a rating response within the allotted time, the last rating the participant had highlighted at that point was taken as their selection. Any time not used in any of the free response intervals was added to the inter-trial-interval, so that a new trial occurred every 34 seconds.
Scenarios. The scenarios were selected for high or low vividness and for positive or negative valence. A list of 68 distinct scenarios was compiled from other studies that assessed vividness, valence, and other aspects of imagination, as well as a survey of MTURK respondents (n = 411, 199 female, average age = 30.1 years, SD = 11 years) who were given broad categories of possible scenarios and asked to create their own. A separate rating study was then performed (n = 131, 73 female, average age = 34.6 years, SD = 12 years) on MTURK in which participants were asked to rate the valence and vividness of imagined scenarios, with each participant rating 17 of the 68 scenarios. Based on these ratings, a final list of 32 scenarios was created by selecting the most and least vivid positive and negative scenarios.

The final stimulus set included 8 scenarios in each of four conditions – Vivid Positive, Vivid Negative, Non-Vivid Positive, and Non-Vivid Negative. These 32 scenarios were repeated with both “near future” and “far future” prompts, where “near future” was defined as “within the next week” and “far future” was defined as “more than a year from now”. This resulted in 64 unique scenario prompts, with each run containing 16 scenarios. We conducted a repeated-measures ANOVA to ensure that there was a main effect of valence and vividness of the scenario on participants’ judgments of valence and vividness.

Imaging Acquisition. Functional and anatomical images were collected using a 3T Siemens Trio scanner equipped with a 32-channel head coil. At the beginning of each session, high-resolution T1-weighted anatomical images were collected using an MPRAGE sequence (T1 = 1100 ms; 160 axial slices, 0.9375 x 0.9375 x 1.000 mm; 192 x 256 matrix). T2*-weighted functional images were collected using an EPI sequence (3 mm isotropic voxels, 64 x 64 matrix, 44 axial slices tilted 30° from the AC-PC plane, TR = 3,000 ms, TE = 25 ms). Each scan consisted of 181 images. All participants completed four scans in each session. At the end of the session we acquired matched B0 fieldmap images (TR = 1000 ms, TE = 2.69 and 5.27 ms).

Imaging Analyses and Preprocessing. Brain imaging analysis was conducted with the FMRIB Software Library (FSL) using FSL FEAT (FMRIB fMRI Expert Analysis Tool) version 6.00 (Smith
et al., 2004). Preprocessing included the following: (1) skull stripping of structural images with BET (FMRIB Brain Extract Tool); (2) motion correcting with MCFLIRT (FMRIB Linear Image Restoration Tool with Motion Correction); (3) spatial smoothing with a 9mm full-width half-maximum Gaussian kernel; and (4) high-pass temporal filtering equivalent to 150 Hz. Registration and normalization was performed with FLIRT. Each functional image was registered to the participant’s high-resolution brain-extracted structural image using boundary-based registration that simultaneously incorporates fieldmap-based geometric distortion, and normalized to the FSL Montreal Neurological Institute (MNI) template using affine transformations with 12 degrees of freedom.

We focused on testing which aspects of the imagined events significantly modulated neural activity in different regions of the brain. Our general linear model included regressors for the Read, Imagine, Rate Vividness, and Rate Valence epochs, as well as categorical event modulators for the Imagine epoch for the Vividness (high versus low), Valence (positive versus negative), and Temporal Distance (near versus far) of the imagined event, and parametric event modulators for the Rate Vividness and Rate Valence epochs (the participant’s rating).

Group analyses focused on the 15s imagination epoch. The main goal of this study was to examine dissociable roles of known DMN subcomponents (identified from previous literature) in future imagination. We first conducted region of interest analyses (ROIs) with masks from Shirer et al. (2012) for the dorsal and ventral default mode networks (Shirer et al., 2012), since full maps of these networks were available for download. Shirer et al. (2012) applied FSL’s MELODIC independent component analysis (ICA) software at the group level for 15 participants who had completed a resting state scan, and defined 90 ROIs. These results were confirmed using peak coordinates for the core and medial temporal lobe (MTL) components of the DMN obtained from Andrews-Hanna et al. (2010) (Andrews-Hanna et al., 2010). Andrews-Hanna et al. (2010) used seed-based functional connectivity procedures to define regions that comprised each subsystem (Andrews-Hanna et al., 2007; Andrews-Hanna et al., 2010). The mean activity for
each DMN subsystem was extracted from the specified image mask using the fslstats command. While the two ways of dividing the DMN are not exactly identical, there is substantial overlap between the dorsal DMN and the DMN core, and between the ventral DMN and the DMN MTL subsystem.

Whole-brain group-level analyses were also performed to assess statistical significance at the whole-brain level on the basis of cluster mass, with the cluster-defining threshold set to the p < 0.001 level. Corrected p-values were determined using permutation testing (FSL randomise; 5000 iterations), and results were thresholded at corrected p < 0.05 to account for multiple comparisons.

Results

Behavioral Results. Behavioral ratings confirmed that we had successfully manipulated the vividness and valence of imagined events. There was a significant effect of vividness (F(3,45) = 31.54, p < 0.001) as well as valence (F(3,45) = 553.91, p < 0.001) in a one-way ANOVA across the four conditions. Vividness ratings were significantly different between vivid (mean = 5.32, SD = 0.36) and non-vivid (mean = 4.39, SD = 0.41) scenarios (t(31) = 10.34, p < 0.01), but not between positive (mean = 4.9, SD = 0.59) and negative (mean = 4.8, SD = 0.63) scenarios (t(31) = 0.84, p = 0.42). Valence ratings were significantly different between positive (mean = 5.72, SD = 0.34) and negative (mean = 2.14, SD = 0.35) scenarios (t(31) = 41.15, p < 0.01). Valence ratings were also slightly more positive for vivid (mean = 4.04, SD = 1.90) than non-vivid (mean = 3.82, SD = 1.80) scenarios (t(31) = 2.29, p = 0.03). Note that each scenario was presented twice, once with a "in the near future" prompt and once with a "in the far future" prompt, but there were no behavioral effects of near versus far future.

Imaging Results. The vividness and valence of imagined events modulated activity in distinct parts of the DMN. To test our hypothesis regarding differential functional roles of previously defined DMN subcomponents, we first examined the division of the DMN into dorsal and ventral
components, as described by Shirer et al. (Shirer et al., 2012). The dorsal and ventral DMN identified by Shirer et al. (Shirer et al., 2012) substantially overlap with the DMN core and DMN MTL divisions as described by Andrews-Hanna and colleagues (2007, 2010 (Andrews-Hanna et al., 2007; Andrews-Hanna et al., 2010)). The dorsal DMN (DMN core) was significantly modulated by valence (mean = 3.65, SE = 1.35) (t(46) = 2.71, p < 0.01), but not vividness (mean = -1.14, SE = 1.26) (t(46) = -0.90, p = 0.37), and the effect of valence was significantly larger than that of vividness (mean = -4.79, SE = 1.62) (t(46) = -2.95, p < 0.01). The ventral DMN (DMN MTL) was significantly modulated by vividness (mean = 3.65, SE = 1.07) (t(46) = 3.41, p < 0.01), but not by valence (mean = -0.63, SE = 0.98) (t(46) = -0.65, p = 0.52), and the effect of vividness was significantly larger than that of valence (mean = 4.37, SE = 1.35) (t(46) = 3.24, p < 0.01) (Figure 2). In addition, valence modulates the dorsal DMN (DMN core) significantly more than the ventral (DMN MTL) (t(23) = -4.48, p < 0.01), while vividness modulates the ventral DMN (DMN MTL) significantly more than the dorsal (DMN core) (t(23) = 5.51, p < 0.01).

This same dissociation was found using the peak coordinates from Andrews-Hanna and colleagues (2007, 2010) (Andrews-Hanna et al., 2007; Andrews-Hanna et al., 2010). The DMN core (dorsal DMN) was significantly modulated by valence (t(46)) = 4.52, p < 0.01), but not vividness (t(46) = -0.78, p = 0.44), and the effect of valence was significantly larger than that of vividness (t(46) = -3.45, p < 0.01). The MTL subsystem of the DMN (ventral DMN) was significantly modulated by vividness (t(46) = 3.13, p < 0.01), but not valence (t(46) = 0.49, p = 0.63), and the effect of vividness over valence was marginally significant (t(46)) = 1.75, p = 0.09) (Figure 3). Note that Andrews-Hanna and colleagues also described a dorsomedial DMN subsystem, but these regions exhibited no significant effects of either vividness (t(46) = -1.62, p = 0.11) or valence (t(46) = -0.62, p = 0.54). In addition, valence modulates the DMN core (dorsal DMN) significantly more than the DMN MTL (ventral DMN) (t(23) = 6.54, p < 0.01), while vividness modulates the DMN MTL (ventral DMN) significantly more than the DMN core (dorsal DMN) (t(23) = -3.84, p < 0.01).
Whole-brain analyses further confirmed the separate modulation of distinct neural regions by vividness and valence. For trials with high compared to low vividness, there was increased activity in the precuneus, hippocampus, and central orbitofrontal cortex (OFC) placed more laterally to vmPFC (Figure 4A). For trials with positive compared to negative valence, there was increased activity in the mPFC and striatum (Figure 4B). Furthermore, activation in the precuneus and parahippocampal gyrus was modulated more by vividness than by valence (Figure 4C), while activation in the mPFC was modulated more by valence than by vividness (Figure 4D). The distinct, non-overlapping activation of frontal cortical regions by valence and vividness is demonstrated in Figure 5. We did not observe any whole-brain or ROI effects for temporal distance (near versus far future).

Discussion

Our results demonstrate a functional double dissociation within the DMN for the first time, by showing the separate modifiability of different subcomponents of the DMN by different aspects of imagination. We manipulated the vividness of imagined events to tax constructive processes during imagination and the valence of imagined events to tax evaluative processes. Vividness, but not valence, modulated activity in the ventral DMN, or DMN MTL subsystem, including precuneus and medial temporal lobe. Valence, but not vividness, modulated activity in the dorsal DMN, or DMN core, including the vmPFC and PCC. This basic pattern held in region of interest analyses using two different sets of DMN ROIs, as well as in whole-brain analyses. These findings support functional specialization within the DMN, with the ventral DMN/MTL subsystem involved in the construction of imagined future events and the dorsal DMN/core involved in the evaluation of imagined future events.

As proposed by Sternberg (2001) (Sternberg, 2001), the kind of separate modifiability demonstrated here between the dorsal and ventral DMN provides strong evidence for dissociable mental modules. The logic of separate modifiability is similar to that of the canonical double
dissociation, though importantly focuses on dissociations between processes within the context of a single task, rather than on dissociations between tasks. Key to the inferential strength of separate modifiability is that different measures (in our case, neural activity in the dorsal and ventral DMN) are shown to be both sensitive and specific (i.e., responding to some manipulations but not others). Given the demonstration of separate modifiability, we can infer that the single complex process of imagination can be decomposed into component processes—putatively, construction and evaluation—which can each be uniquely influenced by the distinct factors of vividness and valence.

To our knowledge, this is the first study to examine neural effects of manipulating both valence and vividness during future imagination in the same individuals. Our findings complement and expand on prior work regarding the role of the DMN in imagination. Many previous studies have shown that imagination and other forms of “mental time travel” engage the DMN as a whole (Botzung et al., 2008; Schacter et al., 2007; Hassabis et al., 2007). With respect to valence, several previous studies have shown, as we do here, that vmPFC is more active when participants imagine positive compared to negative scenarios (Gilbert & Wilson, 2007; Sharot et al., 2007; D’Argembeau & Van der Linden, 2004). Though no previous studies have directly manipulated the vividness of imagined events, hippocampus and precuneus, the regions we find are more active when participants imagine more vivid scenarios compared to less vivid scenarios, are known to be important in episodic scene construction (Addis et al., 2007; Andrews-Hanna et al., 2010; Schacter et al., 2007; Hassabis et al., 2007; Fletcher et al., 1995; Vincent et al., 2006). It is possible that the role of the hippocampus in memory retrieval make it well-positioned to play a role in scene-construction, which involves remembering and integrating features to form a novel event (Summerfield et al., 2010).

Andrews-Hanna et al. (2010) proposed that what they called the MTL subsystem of the DMN (including hippocampus and precuneus) was involved in constructing scenes during imagination of future events, while what they called the core DMN (including the mPFC) was
involved in evaluating the personal significance of both present and future events (Andrews-Hanna et al., 2010). The evidence to support this claim, however, was a single dissociation in which the MTL subsystem showed a greater response to imagining future events, while DMN core was active when thinking about both present and future events. However, other studies have observed different patterns of activity for thinking about the future versus the present, and in our study we found no differences between thinking about events matched in content that were nearer or farther into the future. Therefore, the separate modifiability by vividness and valence demonstrated here provides much stronger support for the distinction originally proposed by Andrews-Hanna and colleagues, between DMN components involved in constructive and evaluative processes during imagination.

We also identified a few regions outside the DMN that were engaged by vividness or valence. The ventral striatum (VS) was more active when imagining positive compared to negative events. This is consistent with the involvement of the vmPFC and VS in evaluating outcomes and encoding predicted value during decision-making tasks (Kable & Glimcher, 2007; Bartra et al., 2013). Interestingly, we observed activation in bilateral orbitofrontal cortex (OFC) for more vivid compared to less vivid scenarios. Several lines of evidence implicate the OFC in decision-making as well, with recent theories proposing that the OFC represents specific outcomes, rather than value itself, that are necessary for computing value and planning during choice tasks (Wallis, 2007; Ursu & Carter, 2005; Bechara et al., 2000). Though there remains much debate over the extent to which OFC and vmPFC may play distinct roles in decision-making, our finding that vmPFC is specifically modulated by valence during imagination, while central OFC is specifically modulated by vividness, supports a distinction between these two closely related areas.

Recent studies suggest that humans spend most of their time engaged in mental time travel, either remembering the past or imagining the future (Killingsworth & Gilbert, 2010). Yet we have very little formal understanding of the psychological processes involved in imagination. Our
results suggest that the complex process of imagination, which might appear to be unitary, can in fact be decomposed into (at least) two dissociable mental processes, the construction of novel potential future events from components in memory and the evaluation of constructed events as desirable or undesirable. Neural measurements provided the key evidence for this dissociation, given the difficulty in constructing objective behavioral measures of imagination quality or ability. Thus neuroscience methods may prove critical to the further understanding of this central aspect of human subjective experience.
Figure 1. Experimental procedure of the imagination fMRI task. Participants had up to 5 secs to read the cue, 15 seconds to imagine, and upto 7 seconds each to rate the vividness and valence of the scenario.
**Figure 2.** ROI results from the dorsal and ventral DMN. This demonstrates that valence but not vividness significantly modulates the dorsal DMN, while vividness but not valence significantly modulates the ventral DMN (**p < 0.01).
Figure 3. ROI results from the DMN core and medial temporal lobe (MTL) subregions. This demonstrates that valence but not vividness significantly modulates the DMN core, while vividness but not valence significantly modulates the DMN MTL system (**p < 0.01).
Figure 4. Whole-brain analysis of vividness, valence, (Viv-Val) and (Val-Viv) contrasts. Panel 3A shows the main effect of vividness, and reveals activity in the hippocampus, precuneus, and central orbitofrontal cortex (x = -10, y = -22, z = -10). Panel 3B shows the main effect of valence, and reveals activity in the vmPFC and ventral striatum (x = 4, z = 0). Panel 3C shows the vividness minus valence contrast, and reveals activity in the precuneus and parahippocampal gyrus (x = -10, y = -38). Panel 3D shows the valence minus vividness contrast and reveals activity in the vmPFC (x = 4, z = 0). All analyses are p < 0.05, cluster corrected.
Figure 5. Whole-brain analysis of valence and vividness. This demonstrates that vividness modulates activity in the central OFC, while valence modulates activity in the vmPFC ($y = 38, z = 0$). All analyses are $p < 0.05$, cluster corrected.
CHAPTER 3 – Neural contributions of vividness and valence in discounting

Abstract

People face many decisions in their daily lives that involve tradeoffs between rewards and time. For example, we must decide whether to eat appetizing desserts now or abstain in favor of health benefits in the future. The tendency to devalue a larger reward available in the future to a smaller reward available immediately is known as delay discounting. While there is individual variability in making these decisions, it is unknown whether discounting the delayed outcome is due to its intangibility or diminished value over time. Distinct neural markers of the vividness and valence of imagined thoughts, obtained from our previous study, provide an opportunity to examine the role of tangibility separate from value during a delay discounting task. We find greater engagement of both vividness and valence-specific regions when delayed outcomes are chosen compared to when delayed outcomes are not chosen, indicating that chosen delayed outcomes are more vivid and valuable than unchosen delayed outcomes. Further, the engagement of vividness-specific regions is greater for higher discounters, suggesting a specific role for constructive networks in individual differences.

Introduction

People often make tradeoffs between a larger reward available after a delay and smaller rewards available immediately. The extent to which an individual devalues, or discounts, the future option is a phenomenon referred to as delay discounting (Kable & Glimcher, 2007). There exists great individual variability in this task (Frederick, 2002). A high discounter displays more impulsive behavior, and is more likely to take the immediate reward, while a low discounter is more patient and willing to wait longer for the larger reward. Frequently choosing immediate rewards in a monetary discounting task is related to engaging in maladaptive behaviors such as drug and alcohol abuse, while waiting for the greater long-term payoff is associated with better educational and financial outcomes (Kirby et al., 1999; Shamosh & Gray, 2008).
One reason why people might discount delayed rewards is that immediate outcomes tend to be concrete, while delayed outcomes tend to be more intangible (Rick & Loewenstein, 2008). For example, when deciding to quit smoking, the immediate effects of withdrawal are concrete, while the delayed effects of having better health is more intangible. However, while delayed outcomes are typically less tangible, this is not necessarily the case. For example, when choosing to go out with friends if there is an exam the next day, one might be able to better imagine the exhaustion the next day rather than enjoying time with friends at the present moment.

Most intertemporal choices involve both time delay and intangibility – do individuals who pick the immediate outcome do so because the other option is delayed or because it is intangible? It is difficult to test whether delayed outcomes are less tangible than immediate ones except through self-report questionnaires or rating scales that assess tangibility. Even if outcomes were rated for tangibility, it would remain difficult to assess whether, and if so, how, tangibility is relevant at the time of choice. Neural evidence is one way to address this question. If the neural signature of tangibility is specific and distinct from value, it allows us to dissociate between brain activity related to tangibility and value and can thus be used to determine if delayed outcomes are more intangible. Additionally, examining the neural signature during choice can help determine the role of tangibility in a discounting task.

Our results from Chapter 2 reveal that there is a neural signature specific for tangibility which is distinct from a neural marker specific for valuation. Participants were given a list of scenarios manipulated for vividness and valence to imagine in the scanner. When looking at neural activity at the time of imagination, region-of-interest analyses revealed a double dissociation between specific nodes of the DMN, such that the ventral (MTL) subsystem of the DMN including medial temporal areas is activated for vividness but not valence, and the dorsal (core) subsystem of the DMN consisting of medial prefrontal areas is activated for valence but not vividness. Additionally, whole-brain results reveal regions specific for vividness, which include the precuneus and parahippocampal gyrus, and areas specific for valence, which include the vmPFC.
Since we have obtained specific regions activated for vividness that are dissociable from specific regions activated for valence, we can use these as neural markers of tangibility and value to look at activation in these areas during intertemporal choices. We hypothesize that a chosen delayed reward will have greater activity in vividness areas than unchosen delayed rewards, consistent with the idea that choices are driven in part by greater tangibility.

**Methods**

**Participants.** Data from 144 participants (aged 18-35) were collected as part of a previous study (Kable et al., 2017, under review). Eligible participants completed a baseline scan during which they performed an intertemporal choice task and risk aversion task. This study will focus on the data from the intertemporal choice task.

**Task.** Participants chose between a smaller immediate reward and a larger reward available after a delay. The immediate reward was fixed ($20 today), and the magnitude and delay of the larger, delayed reward varied from trial to trial. Only the delayed option was presented on the screen, while participants were reminded of the immediate option at the start of each block. There were 4 blocks of the task, each with 30 trials, and separated by a risk sensitivity block in between. Subjects had 4 s to make their choice, and a marker indicating their choice (checkmark if later option was chosen, “X” if the immediate option was chosen) appeared on the screen for 1 s.

**Neuroimaging.** Participants were scanned using BOLD fMRI while completing intertemporal choice and risk sensitivity tasks. The task blocks alternated and the order was counterbalanced across participants. All fMRI scans were performed using a Siemens Trio 3T scanner and a Siemens product 32-channel head coil optimized for parallel imaging. T2*-weighted functional images were collected using an EPI sequence (voxel size 3 mm x 3 mm x 3mm, 64 x 64 matrix, 53 axial slices, TR = 3,000 ms, TE = 25 ms, 104 volumes). A B0 field map was acquired (TR = 1270 ms, TE 1 = 5.0 ms; TE 2 = 7.46 ms) to support off-line estimation of geometric distortion in the functional data. Functional region-of-interest analysis masks from the (Vividness-Valence)
and (Valence-Vividness) contrasts (see Chapter 2, Figures 4C and 4D) were obtained from the study completed in Chapter 2. The (Vividness-Valence) contrast provided vividness-specific regions such as the precuneus and parahippocampal gyrus, while the (Valence – Vividness) contrast provided valence-specific regions such as the vmPFC.

**Behavioral Analysis.** The primary behavioral outcome was discount rate (k). Discount rates were estimated using a logistic regression model in MATLAB (Mathworks). Participants’ choice data were fit with the following logistic function using maximum likelihood estimation:

\[
P_1 = 1 + e^{-\beta (SV_1 - SV_2)}, \quad P_2 = 1 - P_1
\]

where \( P_1 \) refers to the probability that the subject chose option 1, and \( P_2 \) refers to the probability that the subject chose option 2. \( SV_1 \) and \( SV_2 \) refer to the participant’s estimated subjective value of option 1 and option 2, and \( \beta \) is used as a scaling factor. The subjective value of the options were estimated using a hyperbolic function:

\[
SV = A(1 + kD)
\]

where \( A \) is the reward amount, \( D \) is the delay, and \( k \) is the participant’s discount rate parameter (Kable & Glimcher, 2007). Larger values of \( k \) indicate a greater degree of discounting future rewards. To account for the fact that discount rates are not normally distributed, all statistics were performed on the log-transformed discount rates.

**Neuroimaging Analysis.** Image processing and analyses were conducted with the FMRIB Software Library (FSL) version 5.08. Functional images were motion corrected using MCFLIRT, high-pass filtered (cutoff at 104 s), distortion corrected with the B0 map, and spatially smoothed with a 9mm FWHM kernel. Subject level analyses were performed using FSL FEAT. Task regressors were time-locked to trial onset and convolved with a canonical gamma hemodynamic response function. In this study, we focus on a model containing one regressor during the time of
choice, and a second regressor modeling the difference between when the delayed option was chosen relative to when the delayed option was unchosen (immediate chosen).

Region of interest analyses were conducted in the regions found to be activated in the (Viv-Val) and (Val-Viv) contrasts from the previous study (Chapter 2, Figures 4C and 4D). The (Viv-Val) contrast included the precuneus and parahippocampal gyrus, while the (Val-Viv) contrast included the vmPFC. The mean activity for each contrast was extracted from the specified image mask using the fslstats command. Correlations were conducted between BOLD activity for the (Viv-Val) and (Val-Viv) contrasts and discount rates for individuals.

Results

There was increased activity in both vividness-specific (mean = 154.31, SE = 37.48) \( t(143) = 4.11, p < 0.01 \) and valence-specific (mean = 145.17, SE = 60.28) \( t(143) = 2.41, p = 0.02 \) regions when participants chose the delayed option compared to when they chose the immediate option (Figure 1). There was no difference in this effect between the vividness- and valence-specific regions \( t(143) = 0.19, p = 0.85 \). There was also a significant correlation between log-\( k \) values and increased activity in the vividness-specific regions \( r = 0.19, p = 0.02 \) (Figure 2), which was only a trend in the valence-specific regions \( r = 0.14, p = 0.09 \) (Figure 3), such that greater activity for delayed choices was associated with higher discount rates.

Discussion

Our results from Chapter 2 allowed us to use activity in vividness- and valence-specific regions during imagination as neural markers of tangibility and value to examine how these factors might be separately involved in intertemporal choice. Our results from Chapter 3 reveal greater activity in vividness-specific regions when participants chose the delayed option, suggesting that chosen delayed outcomes are in fact, processed as being more tangible than unchosen delayed outcomes.
The activity seen in the valence-specific (prefrontal) regions is consistent with prior literature on positive valence and valuation (Sharot et al., 2008, D’Argembeau et al., 2008, Kable and Glimcher, 2007). However increased activity seen in vividness regions suggest that participants are imagining the chosen delayed outcome more vividly than the chosen immediate outcome or engaging the constructive process of imagination to a greater extent.

This is based on a reverse-inference assumption that activity in the vividness-specific regions is a specific marker of engaging in constructive thought. While it may be the case that other factors may influence activity in these areas, our dissociation results from Chapter 2 reveal that the vividness- and valence-specific regions are distinct from each other. Vividness-specific regions are not modulated by activity attributed to value, and valence-specific regions are not modulated by activity due to tangibility. This suggests that while there may be other alternative factors that might modulate activity in vividness-specific regions, value is unlikely to be a confound. A similar principle is applied in multi-variate pattern analysis (MVPA). MVPA applies machine learning to brain activation patterns to predict the engagement of a specific mental process, and subsequent use of these multivariate patterns to index or operationalize engagement of that process rely on a similar reverse inference.

Interestingly, our correlation results reveal a positive relationship between discount rates and BOLD activity in the vividness regions, such that higher discounters have greater differential activity (delayed option chosen > unchosen) in these areas. This could have several implications. Higher discounters could vividly imagine the future to a greater extent than lower discounters. Another interpretation is that higher discounters may not have more vivid imaginations per se, but could rely on vividness cues to a greater extent during choice than lower discounters. Both of these interpretations are consistent with the construal theory and the notion that being in a concrete mindset could in fact lead to present-bias (Rick & Loewenstein, 2008; Malkoc & Zauberman, 2010, Trope & Liberman, 2010). High discounters could enhance vividness for the present as well as the future, thus leading them to make more impulsive choices overall.
However, this is inconsistent with previous work on imagination suggesting that enhancing vividness or tangibility increases choice of the delayed reward (Peters & Buchel, 2010; Benoit et al., 2011). To further examine this discrepancy, we specifically manipulate vividness in experiments in Chapter 4 and look at the effects on discounting behavior.

One limitation of this study is that the delay for chosen outcomes for high discounters would be lower than the delay of chosen outcomes of lower discounters. In addition, there would be fewer chosen delayed options for high discounters compared to low discounters. These would both be confounds to be eliminated in future studies to better understand the mechanism of vividness activation in high discounters.

An interesting future direction could be to behaviorally test the effects of training visualization to see its effects on choice. We find greater engagement of vividness-specific regions for chosen delayed rewards, suggesting that imagining the future more vividly at the single choice level would perhaps lead to more patient behavior. However, since we find stronger activity in vividness-specific regions for high discounters, it suggests that these individuals are more likely to rely on vividness cues during choice than low discounters. Therefore, enhancing visualization abilities might in fact lead to steeper discounting. As will be seen in Chapter 4, we find that training individuals to be better visualizers is associated with more impulsive behavior.
Figure 1. Activity in vividness-specific and valence-specific regions during choice. There was significant activity in the vividness ($t(143) = 4.11, p < 0.01$) and valence (mean $= 145.17$, SE $= 60.28$) ($t(143) = 2.41, p = 0.02$) regions when participants chose the delayed option compared to when they did not choose the delayed option (chose immediate). There was no difference between the vividness and valence regions ($t(143) = 0.19, p = 0.85$).
Figure 2. Correlation between log-k and activity in vividness-specific regions. There was a significant correlation between log-k values and activity in the vividness regions ($r = 0.19$, $p = 0.02$).
Figure 3. Correlation between log-k and valence-specific regions. The correlation between log-k values and activity was not significant in the valence regions \( (r = 0.14, p = 0.09) \).
CHAPTER 4 – The vivid present: Visualization abilities are associated with steep
discounting of future rewards

Abilities Are Associated with Steep Discounting of Future Rewards. Front. Psychol. 8:289.

Abstract

Humans and other animals discount the value of future rewards, a phenomenon known
as delay discounting. Individuals vary widely in the extent to which they discount future rewards,
and these tendencies have been associated with important life outcomes. Recent studies have
demonstrated that imagining the future reduces subsequent discounting behavior, but no
research to date has examined whether a similar principle applies at the trait level, and whether
training visualization changes discounting.

The current study examined if individual differences in visualization abilities are linked to
individual differences in discounting and whether practicing visualization can change discounting
behaviors in a lasting way. Participants (n = 48) completed the Visualization of Vivid Imagery
Questionnaire (VVIQ) and delay discounting task and then underwent a four-week intervention
consisting of visualization training (intervention) or relaxation training (control). Contrary to our
hypotheses, participants who reported greater visualization abilities (lower scores) on the VVIQ
were higher discounters. To further examine this relationship, an additional 106 participants
completed the VVIQ and delay discounting task. In the total sample (n= 154), there was a
significant negative correlation between VVIQ scores and discount rates, showing that individuals
who are better visualizers are also higher discounters. Consistent with this relationship but again
to our surprise, visualization training tended, albeit weakly, to increase discount rates, and those
whose VVIQ decreased the most were those whose discount rates increased the most. These
results suggest a novel association between visualization abilities and delay discounting.
Introduction

Humans often make decisions that involve tradeoffs between immediate and delayed consequences. For example, smokers enjoy the immediate pleasure of smoking a cigarette even though they may understand the long-term consequence of continued use. The extent to which an individual rejects large rewards in the future to obtain smaller rewards available immediately is known as delay discounting (Kable & Glimcher, 2007). Humans and other animals frequently discount the delayed consequences of their actions (Chung & Herrnstein, 1967; Rachlin et al., 1991; Frederick, 2003; Mazur, 1984). A reward that is delayed has a reduced effect on behavior compared to the same reward provided immediately. In humans, delay discounting can be measured by giving people choices between immediate and delayed rewards and using these choices to estimate their discount rate, an index of the extent to which the value of delayed rewards is discounted relative to immediate ones. Discount rates vary widely across individuals (Kable & Glimcher, 2007; Frederick, 2002), but are remarkably stable across time within an individual (Senecal et al., 2012; Baker et al., 2003; Ohmura et al., 2006; Kirby et al., 2009). Higher discount rates (steeper discounting) are associated with a variety of maladaptive behaviors, including drug and alcohol abuse, smoking, and obesity (Madden & Bickel, 2010; MacKillop et al., 2011; Petry, 2001; Audrain-McGovern et al., 2004; Kirby et al., 1999; Kirby & Petry, 2004). High discount rates are also associated with poorer academic performance (Duckworth & Seligman, 2005; Kirby, Winston, & Santiesteban, 2005), a greater likelihood of mortgage default (Meier & Sprenger, 2012), and greater likelihood of divorce (Reimers et al., 2009). Given these associations between steep discounting and important life outcomes, there is keen interest in understanding the psychological processes that drive individual differences in discounting, and in developing interventions that could impact discounting in a lasting way.

One process that could account for individual differences in discounting is an individual’s ability to vividly imagine future outcomes. Some theoretical accounts of discounting stress how delayed outcomes are less vivid or less concrete than immediate outcomes (Rick & Loewenstein,
Related computational models show how discounting could arise from a prospective process that mirrors retrospective memory – akin to a distant memory, an outcome in the far future is harder to bring to mind (Kurth-Nelson et al., 2012). While speculative, these process models could be linked to normative models that provide reasons for discounting future outcomes based on their uncertainty (Sozou, 1998; Redish & Kurth-Nelson, 2010), if vividness serves as a psychological cue for the certainty of a future outcome. Functional imaging studies support the notion that discount rates may depend on such prospective processes. Blood-oxygen level dependent (BOLD) signal in ventromedial prefrontal cortex (vmPFC), a region engaged when individuals are simply imagining the future, predicts individual discount rates (Cooper et al., 2013; Ersner-Hershfield et al., 2008; Mitchell, 2009). Specifically, lower discounters exhibited greater vmPFC activation when thinking about the far future, while higher discounters exhibited greater vmPFC activation when thinking about the near future (Cooper et al., 2013). In addition to these links to individual differences, recent studies have shown how engaging visualization processes can change discounting. Several studies have now demonstrated that asking people to call to mind a future event reduces the extent to which they discount a delayed reward in a subsequent choice, and the size of this effect is correlated with the vividness of the imagined event (Benoit, et al., 2011; Liu et al., 2013; Peters & Büchel, 2010; Lin & Epstein, 2014).

However, the effects of imagining a future event on discounting that have been demonstrated to date are short-lived and do not seem to persist past the immediately subsequent choice. Whether there are more stable associations between the ability to imagine future events and discounting, and whether these abilities can be altered in a longer-lasting manner, is unknown. In the current study, we ask if individual differences in visualization are linked to individual differences in discounting, and whether these abilities and discounting can be changed in a lasting way after training in visualization. We hypothesized based on previous work that a greater ability to vividly imagine events would be associated with reduced discounting, and that
visualization training would lead to a decrease in discount rates. Surprisingly, though, we found the opposite association, and furthermore practice with visualization tended to both increase the ability to vividly imagine and to increase discounting.

**Methods**

*Visualization Training Intervention Experiment*

*Participants.* Forty-eight paid volunteers (33 females, 15 males; mean age = 24.6 years, SD = 6.5 years) from the University of Pennsylvania community participated in this study examining the effects of visualization training on discounting. All participants were healthy adults without any physical and/or mental illnesses. Ten participants did not complete the training period and therefore did not return for a follow-up visit to complete the study. The mean age of the final sample (N=38, 28 females, 10 males) was 24.7 years (SD= 6 years). All participants provided consent in accordance with the procedures of the Institutional Review Board of the University of Pennsylvania.

*Tasks.* All participants completed two testing sessions, an intake session before the intervention (range = 8-28 days, median = 18 days) and a follow-up after the intervention (range = 3-19 days, median = 7 days). At each visit, participants completed the same battery of decision-making tasks and self-report questionnaires. Before the intake session, participants were randomly placed into either the intervention group (visualization training) or the control group (relaxation training). The final sample consisted of 20 participants in the intervention group and 18 in the control group. At the end of the intake session, those in the intervention group were also asked to write down 4-6 goals that they hope to achieve in the future.

All participants completed five decision-making tasks, presented on a computer using E-Prime (Psychology Software Tools, Sharpsburg, PA). Tasks were presented in a random order for each subject. *Our a priori* hypotheses concerned the intertemporal choice (ITC) task. The ITC task consisted of 102 choices, adopted from Senecal et al. (2012), Experiment 3. Each choice
was between a smaller monetary reward available immediately or a larger reward available after a delay. Amounts for smaller rewards ranged between $10-$34, and amounts for larger rewards were $25, $30, $35. The delays ranged from 1-180 days. All participants were presented with the same choices in a random order.

Four additional decision-making measures were administered for exploratory purposes: risk aversion, in which participants chose between a smaller amount of money that was certain and a larger amount that was risky (50% chance of receiving the reward, Levy et al., 2009); loss aversion, in which participants chose whether to take a gamble with a 50% chance of winning some amount and a 50% chance of losing a larger or smaller amount (Tom et al., 2007); ambiguity aversion, in which participants chose between playing a lottery with a fixed 50% chance of winning and another lottery where the reward was greater but the probability of winning was uncertain (Levy et al., 2009); and a task that measures the balance of model-based versus model-free reinforcement learning (Glascher & Buchel, 2005). As these tasks do not bear on our a priori hypotheses, detailed results from these measures will not be included in this paper.

Questionnaires. Following the battery of decision-making tasks, six self-report questionnaires were administered to participants using Qualtrics Online Surveys. The Vividness of Visual Imagery Questionnaire (Marks, 1973) was of main interest. The VVIQ is a 16-item questionnaire that measures individual differences in vividness of visual imagery. The questionnaire instructs participants to imagine different scenarios and subsequently rate their imaginations on a 4-point scale. Studies have reported an internal consistency reliability of 0.96 for the VVIQ (Campos, 2011; Rossi, 1977; Richardson, 1994; McKelvie, 1995). The VVIQ was used to test for an association between vividly imagining events and delay discounting, and as a manipulation check to ensure that visualization training in fact affected the ability to vividly imagine events. The remaining five questionnaires were exploratory to test for other possible effects of the visualization training on self-reported traits: the Attributional Style Questionnaire (Peterson et al., 1982), measuring optimistic and pessimistic explanatory styles; the General Self-Efficacy
Scale (Schwarzer & Jerusalem, 1995), assessing perceived self-efficacy; the Life Orientation Test (revised) (Scheier, Carver & Bridges, 1994), measuring dispositional optimism; the Zimbardo Time Perspective Inventory Questionnaire (Zimbardo & Boyd, 1999), assessing orientation and attitudes towards time; and the Interpersonal Reactivity Index (Davis, 1983), measuring dispositional empathy and perspective taking.

Training. The training period lasted four weeks. For both groups, the training consisted of several one-hour guided meditation sessions conducted in a group, as well as five-minute online podcasts participants could listen to on their own.

The one-hour in-person guided meditation sessions were held in the Meditation Room of the Graduate Student Lounge at the University of Pennsylvania. Each intervention group underwent separate meditation sessions, offered two days a week, one in the evening and one mid-day. All sessions were led by the same instructor, a Health and Wellness Educator at the University of Pennsylvania and an experienced meditation and mindfulness instructor. Participants were asked to complete at least six of the eight in-person sessions offered to their group.

The meditation sessions for both groups were one hour long and began with the same relaxation cues. For the visualization training group, this was followed by goal-oriented guided visualization. Participants were told to focus on a goal that they would like to achieve in the future and were led through two vivid scenarios in which they could imagine overcoming the obstacles in their way and experiencing the feelings accompanying achievement of the goal. The meditation sessions for the control group consisted of guided relaxation, without visualization or future thinking. Participants were told to bring awareness to their body and breath, and focused on the physical sensations they were experiencing in the present moment. (See Supplementary Material for full-length scripts).
The online podcasts were five-minute voice recordings by the same instructor, designed to be a shortened version of the in-person sessions. Participants were asked to listen to the podcast at least six times a week during the training period.

*Payment.* Participants were paid a show-up fee of $15.00 for the intake visit and $10.00 for the follow-up. At both visits, participants were aware that they could also receive an additional incentive-based payment according to their choices in one of the five decision-making tasks. Each decision making task was designed to be incentive compatible. At the end of each session, the participant rolled a die to choose which of the five tasks would determine their payment. With the exception of the learning task, which was paid based on total performance, participants rolled a die again to determine the choice within that task for which they would be paid. For the ITC task, participants were paid using a Ficentive gift card (Sunrise Banks N.A., St. Paul, MN), which was loaded with their earnings either the same day if they chose the immediate option, or after the specified delay if they chose the later option. Any gambles selected were resolved by flipping a coin (risk aversion, loss aversion) or drawing a poker chip from an envelope (ambiguity aversion).

For the training, participants received $10.00 for every one-hour meditation session they attended and $1.00 for every 5-minute audio podcast they listened to.

*Data Analysis.* Discount rates were estimated using a logistic regression model in MATLAB (Mathworks). Participants’ choice data were fit with the following logistic function using maximum likelihood estimation:

\[
P_1 = 1 + e^{-\beta(SV_1 - SV_2)} , \quad P_2 = 1 - P_1
\]

where \(P_1\) refers to the probability that the subject chose option 1, and \(P_2\) refers to the probability that the subject chose option 2. \(SV_1\) and \(SV_2\) refer to the participant's estimated subjective value of option 1 and option 2, and \(\beta\) is used as a scaling factor. The subjective value of the options were estimated using a hyperbolic function:
$SV = A1 + kD$

where $A$ is the reward amount, $D$ is the delay, and $k$ is the participant's discount rate parameter (Kable & Glimcher, 2007). Larger values of $k$ indicate a greater degree of discounting future rewards. To account for the fact that discount rates are not normally distributed, all statistics were performed on the log-transformed discount rates.

Since subjects were randomized to group and discount rates are known to be stable over time, we planned to evaluate the effects of visualization training using (1) a between groups $t$-tests comparing the visualization and relaxation groups after training, and (2) a paired-sample $t$-test testing within subjects differences in the visualization group between intake and follow-up. We also performed a between groups $t$-tests comparing changes after training in the two groups, equivalent to evaluating the interaction term in a mixed ANOVA. Pearson correlation coefficients were computed to assess the relationship between discount rates and self-report measures.

Additional Samples Assessing Individual Differences

To allow us to examine the relationship between VVIQ and discount rates in a larger sample, we collected these measures in two additional experiments. Another 106 paid volunteers from the University of Pennsylvania community were recruited as part of two different studies examining the effects of different manipulations on discount rates. The first study included 49 subjects (30 females, 19 males; mean age = 23.3 years, SD = 3.6 years), while the second study included 57 subjects (36 females, 21 males; mean age = 22.3 years, SD = 3.3 years). All participants provided consent in accordance with the procedures of the Institutional Review Board of the University of Pennsylvania.

In both studies, participants came in on the first day and completed the same ITC task (102 questions) and VVIQ as in the visualization training intervention experiment. While the first study had no additional tasks or questionnaires on that first day, participants in the second study completed four other self-reports including the Gratitude Questionnaire (McCullough et al., 2002), which measures individual differences in the level of gratitude; the Grit Scale (Duckworth et al.,
2007), which measures individual differences in perseverance and passion towards long-term goals; the Brief Mood Introspection Scale (Mayer and Gaschke, 1988), which measures current mood; and the Life Orientation Test (revised) (Scheier, Carver & Bridges, 1994). Participants in both studies continued on to a second day that involved a test of the effects of different manipulations on discount rates, but those results are not discussed here.

Participants were paid $10.00 an hour and received an additional incentive-based payment according to their choices in the ITC task (as outlined above). Discount rates and VVIQ scores were calculated in the same manner as above.

**Results**

Contrary to our hypothesis, we found that people who reported more vivid visual imagery were higher discounters. In the participants in our visualization training study, at baseline, VVIQ was significantly negatively correlated with log-k values ($n = 48$, $r = -0.37$, $p = 0.02$, note that lower VVIQ scores represent more vivid visual imagery, Figure 1). In other words, people with a greater capacity to imagine scenarios vividly on the VVIQ were less likely to select the larger delayed rewards in the intertemporal choice task. Since this result was in the opposite direction of our prediction, we collected VVIQ and discount rate data from additional subjects to evaluate the robustness of this relationship in a larger sample. Across all subjects ($n = 154$), the negative relationship between VVIQ and log-k values was attenuated but still statistically significant ($r = -0.25$, $p < 0.01$, Figure 2), indicating that individuals who were more vivid visualizers (lower VVIQ scores) were higher discounters (higher log-k values). This relationship persists when controlling for age, gender, and education ($R^2 = 0.09$, $F(4,149) = 3.737$, $p < 0.01$, $b = -0.209$, $t(149) = -2.599$, $p = 0.01$). Associations between other individual difference measures and discount rates or VVIQ are reported in Table 1.

Returning to our visualization training study, we examined the effects of the visualization training on VVIQ scores. Consistent with our expectations, visualization training tended to
increase the vividness of visual imagery, though this effect was not robust. After training, the visualization group (mean = 29.1, SE = 2.23) had significantly lower VVIQ scores than the control group (mean = 37.33, SE = 3.08) (t(36) = 2.20, p = 0.03, Figure 3). Note that there was no significant difference between the intervention (mean = 32.75, SE = 2.18) and control (mean = 36.56, SE = 2.85) groups prior to training (t(36) = 1.07, p = 0.29). However, there was no significant effect of training on VVIQ within the visualization group (t(19) = 1.54, p = 0.14; similar test in the control group, t(17) = 0.81, p = 0.43), and the interaction between group (intervention versus control) and time (pre- versus post-training) on VVIQ did not reach significance (t(36) = -1.66, p = 0.11).

We next examined the effects of visualization training on discounting. Contrary to our hypothesis, but consistent with the observed relationship between VVIQ and discount rates, visualization training tended to increase discount rates, though again this effect was not robust. After training, the visualization group (mean = -1.70, SE = 0.19) had significantly higher discount rates (t(36) = 2.16, p = 0.04) than the controls (mean = -2.26, SE = 0.17) (Figure 4). Note that there was no significant difference between the intervention (mean = -1.93, SE = 0.81) and control (mean = -2.33, SE = 0.60) groups prior to training (t(36) = 1.73, p = 0.09). However, there was no significant effect of training within the visualization group (t(19) = 1.83, p = 0.08; similar test in control group, t(17) = 1.04, p = 0.31), and the interaction between group (intervention versus control) and time (pre- versus post-training) did not reach significance (t(36) = 0.28). Exploratory tests revealed no effects of training on any other measure (Table 1).

Finally, we found that changes in discount rates after training were correlated with changes in the vividness of visual imagery. As at baseline, VVIQ and discount rates were negatively correlated after training (n = 38, r = -0.45, p < 0.01 at follow-up). Furthermore, there was a significant relationship between change in log discount rate from pre- to post-training and change in VVIQ (r = -0.44, p = 0.006). Individuals whose vividness of visual imagery increased the most were those whose discount rates increased the most (Figure 5).
Discussion

Here we found that increased trait visualization abilities are associated with increased discount rates. In a total sample of 154 subjects, there was a significant negative correlation between VVIQ scores and discount rates, showing that individuals who are better visualizers are also higher discounters. Furthermore, consistent with this association between visualization abilities and discounting, we found that one month of repeated practice of visualizing one’s future goals tended, albeit weakly, to increase discounting of future rewards. After the intervention, participants in the visualization group had significantly higher discount rates than participants in the control group who performed relaxation exercises without visualization. Causal inference about the effect of the intervention, though, is weakened by the fact that the group by time interaction was not statistically significant. The intervention study did provide further correlational evidence for the relationship between visualization and discounting, as post-intervention changes in VVIQ were significantly negatively correlated with changes in discount rate. Taken as a whole, these findings provide converging support for the idea that the ability to vividly imagine scenes is associated with higher discount rates.

Given the growing evidence that instructing subjects to imagine future events leads them to discount less in subsequent choices (Peters and Buchel, 2010; Benoit et al., 2010; Liu et al., 2013, we had predicted the opposite association, that more vivid imagers would discount less and that visualization training would reduce discounting. Why might visualization abilities, as assessed by the VVIQ, be associated with steeper discounting?

One possibility is that since questions on the VVIQ ask subjects to visualize items in the present, the VVIQ specifically taps into the ability to visualize the present, perhaps at the expense of the future. If VVIQ measures visualization of the present, however, it is unclear why practice visualizing future goals would change VVIQ, as we observed.

A second possibility is that the ability to vividly imagine can be directed at the present and the future, and on balance yields further advantage for the already vivid present in tradeoffs.
between the two. Past research has shown that visualization in a concrete mindset raises levels of present-bias, which in turn increases impulsivity (Malkoc et al., 2010; Malkoc & Zauberman, 2006). Similarly, in classic experiments on delay of gratification, manipulations that increased the vividness of both outcomes (e.g., placing both rewards in front of the children) reduced delay of gratification and increased impulsivity (Mischel & Ebbesen, 1970).

A third possibility is that visualizing one’s future goals, in isolation, reduces rather than enhances one’s motivation towards those goals. Imagining achieving one’s future goals may serve as proxy for fulfilling those goals. In addition, visualizing goals that one has not yet reached, and the potential roadblocks to those goals, might have provoked anxiety and avoidance. Indeed, post-experiment feedback from some participants suggested that visualization training may have also enhanced visualization of the obstacles to achievement. This focus on goals that might not be achieved may lead to a sense of deprivation that promotes increased impulsivity (Hoch & Loewenstein, 1991; Rachlin & Raineri, 1992). These possibilities are further supported by the literature on mental contrasting, which shows that imaging future goals alone does not improve success in achieving those goals, unless accompanied by making concrete plans as to how to achieve those goals (i.e., implementation intentions) (Oettingen et al., 2015; Kappes et al., 2013; Oettingen, 2000; Gollwitzer & Sheeran, 2006).

Each of these three possible explanations for the trait associations we observed can be reconciled with reported state effects of imagination that go in the opposite direction, given that participants in these studies imagine only future events, and these events are typically already planned or easily possible rather than highly desired goals (Peters & Buchel, 2010; Benoit et al., 2011, Lin & Epstein, 2014). Nonetheless, our results also lead us to reconsider potential explanations for why imagining future events has been shown to reduce discounting. In light of our results, it is possible that engaging in prospective thought or vivid imagination does not by itself drive these effects, but rather that imagining certain kinds of future events engenders positive emotions or reduces arousal that subsequently decreases discounting. This hypothesis is
consistent with several studies regarding the influence of affect and arousal on discounting (Kim and Zauberman, 2013; Lerner et al., 2012), and would explain why in some cases imagining future events increases rather than decreases discounting. For example, Liu et al., 2013, found that participants were more likely to choose the immediate reward when imagining negative future events compared to no imagination; Lempert and Pizzagalli, 2010, demonstrated that when a stressor is present, imagining an event in the future increases preferences for immediate reward. (Liu et al., 2013; Lempert and Pizzagalli, 2010); and Senecal et al., 2012, showed that engaging in prospective thought can, depending on the content of such thought, either increase or decrease discounting of delayed rewards.

Of course, it is also possible that our reported trait associations are not about imagination per se, but rather another personality trait associated with vivid visualization. For example, extraversion has been associated with lower VVIQ scores, with more extroverted individuals reporting more vivid imagination (McDougall & Pfeifer, 2012). It has also been reported that extroverted individuals are higher discounters (Hirsh et al., 2010, Hirsh et al., 2008, Ostaszewski, 1996), though not all studies find this (Manning et al., 2014, Becker et al., 2012), and reported associations are often moderated by other variables, such as cognitive ability (Hirsh et al., 2008) or current levels of positive mood (Hirsh et al., 2010). Since our study did not measure extraversion, it is possible that this trait could account for some of the relationship between visualization and discounting.

A few caveats to this study warrant mention. Both the training and the VVIQ assessment involved visualization activities that are fundamentally internal and subjective and thus difficult to verify. In addition, VVIQ scores could be affected by participants’ potentially faulty sense of how their own imagery compares to other people. Beyond this subjectivity, the podcast segment of the intervention was completed at home under conditions we were unable to monitor. Overall, we believe these considerations would have made it more difficult for us to detect effects of visualization training. We also cannot conclude that there are no favorable effects of visualization
training. Though none of our exploratory variables showed any change, we measured a limited set of variables. We were also unable to assess whether participants in the visualization group were more successful in achieving their goals than they otherwise would have been. Despite these caveats, our results provide novel evidence for an association between the vividness of visual imagery and discount rates. These results help to further delineate the complex relationship between episodic future thinking, vivid and concrete imagery, and delay discounting. Imagining possibilities more vividly may not always be the most productive path to increased patience.
Table 1. Relationship between ITC and VVIQ and all other tasks and self-reports administered in the visualization intervention experiment. The first column shows the correlation with log-k values pre-training, and the second column shows the correlation with VVIQ scores pre-training, and the third column tests for group differences between visualization and relaxation groups post-training.

<table>
<thead>
<tr>
<th>Tasks</th>
<th>Correlation with ITC pre-training</th>
<th>Correlation with VVIQ pre-training</th>
<th>Group differences post-training</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha, Risk Aversion</td>
<td>r = 0.27, p = 0.07</td>
<td>r = -0.19, p = 0.20</td>
<td>t(36) = 1.29, p = 0.21</td>
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<tr>
<td>Lambda, Loss Aversion</td>
<td>r = 0.00002, p = 0.99</td>
<td>r = -0.08, p = 0.59</td>
<td>t(36) = 0.54, p = 0.59</td>
</tr>
<tr>
<td>Beta, Ambiguity Aversion</td>
<td>r = 0.42, p &lt; 0.01</td>
<td>r = -0.39, p &lt; 0.01</td>
<td>t(36) = 0.61, p = 0.54</td>
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<tr>
<td><strong>Self-Reports</strong></td>
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<tr>
<td>Life Optimism Test – Revised</td>
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<tr>
<td></td>
<td>r = -0.01, p = 0.95</td>
<td>r = -0.25, p = 0.09</td>
<td>t(36) = -0.88, p = 0.38</td>
</tr>
<tr>
<td>Zimbardo Time Perspective Inventory</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Past Negative</td>
<td>r = 0.10, p = 0.50</td>
<td>r = 0.10, p = 0.50</td>
<td>t(36) = -0.39, p = 0.70</td>
</tr>
<tr>
<td>Present Hedonistic</td>
<td>r = 0.13, p = 0.38</td>
<td>r = -0.27, p = 0.06</td>
<td>t(36) = 0.20, p = 0.84</td>
</tr>
<tr>
<td>Future</td>
<td>r = -0.001, p = 0.99</td>
<td>r = -0.07, p = 0.64</td>
<td>t(36) = 0.55, p = 0.58</td>
</tr>
<tr>
<td>Past Positive</td>
<td>r = -0.06, p = 0.71</td>
<td>r = -0.19, p = 0.20</td>
<td>t(36) = -1.16, p = 0.25</td>
</tr>
<tr>
<td>Present Fatalistic</td>
<td>r = 0.17, p = 0.25</td>
<td>r = -0.07, p = 0.64</td>
<td>t(36) = -0.45, p = 0.65</td>
</tr>
<tr>
<td>Interpersonal Reactivity Index</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perspective-Taking (PT)</td>
<td>r = 0.41, p &lt; 0.01</td>
<td>r = -0.45, p &lt; 0.01</td>
<td>t(36) = 0.47, p = 0.64</td>
</tr>
<tr>
<td>Fantasy (FS)</td>
<td>r = 0.32, p = 0.03</td>
<td>r = -0.34, p = 0.02</td>
<td>t(36) = 0.09, p = 0.93</td>
</tr>
<tr>
<td>Empathic Concern (EC)</td>
<td>r = 0.22, p = 0.13</td>
<td>r = -0.21, p = 0.15</td>
<td>t(36) = -0.23, p = 0.82</td>
</tr>
<tr>
<td>Personal Distress (PD)</td>
<td>r = 0.30, p = 0.04</td>
<td>r = -0.13, p = 0.38</td>
<td>t(36) = 0.03, p = 0.97</td>
</tr>
<tr>
<td>Self-Reports (continued)</td>
<td>Correlation with ITC pre-training</td>
<td>Correlation with VVIQ pre-training</td>
<td>Group differences post-training</td>
</tr>
<tr>
<td>--------------------------</td>
<td>----------------------------------</td>
<td>----------------------------------</td>
<td>--------------------------------</td>
</tr>
<tr>
<td>Self-Efficacy Scale</td>
<td>n = 48</td>
<td>n = 48</td>
<td>n = 38</td>
</tr>
<tr>
<td></td>
<td>r = -0.007, p = 0.96</td>
<td>r = -0.24, p = 0.10</td>
<td>t(36) = -0.60, p = 0.55</td>
</tr>
<tr>
<td>Attributional Style</td>
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</tr>
<tr>
<td>Questionnaire</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Good</td>
<td>r = 0.09, p = 0.54</td>
<td>r = 0.10, p = 0.50</td>
<td>t(36) = 0.28, p = 0.78</td>
</tr>
<tr>
<td>Bad</td>
<td>r = -0.0001, p = 0.99</td>
<td>r = 0.02, p = 0.89</td>
<td>t(36) = -0.57, p = 0.57</td>
</tr>
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</table>
Figure 1. Correlation between log-k values and VVIQ scores. VVIQ scores are significantly correlated with log-k values both at intake (n = 48, r = -0.37, p = 0.02) and at follow-up (n = 38, r = -0.45, p < 0.01).
Figure 2. Correlation between log-k values and VVIQ scores for 154 subjects. VVIQ scores were significantly correlated with log-k values across all subjects in all experiments (n = 154, r = -0.25, p < 0.01).
Figure 3. Visualization training decreases VVIQ scores. The visualization group had significantly lower VVIQ scores (i.e., were more vivid visualizers) after training ($t(36) = 2.20, p = 0.03$), while there was no significant difference between the two groups before training ($t(36) = 1.07, p = 0.29$). However, there was no significant effect of training within either group ($t(38) = 1.54, p = 0.14$ for visualization and $t(34) = 0.81, p = 0.43$ for control), and the interaction between group and time on VVIQ did not reach significance ($t(36) = -1.66, p = 0.11$).
Figure 4. Visualization training increases log-k values. The visualization group had significantly higher discount rates (i.e., were more impatient) after training \((t(36) = 2.16, p = 0.04)\), while there was no significant difference between the two groups before training \((t(36) = 1.73, p = 0.09)\). However, there was no significant effect of training within either group \((t(38) = 1.83, p = 0.08)\) for visualization and \((t(34) = 1.04, p = 0.31)\) for control), and the interaction between group and time on discount rates did not reach significance \((t(36) = 1.10, p = 0.28)\).
Figure 5. Correlation between changes in log-k values and changes in VVIQ scores. Changes in log-k values after training were significantly correlated with changes in VVIQ scores ($r = -0.44$, $p < 0.01$).
CHAPTER 5 – General Discussion

Many decisions in our everyday lives involve making tradeoffs between larger, delayed rewards and smaller, immediate rewards. There is significant individual variability in how individuals make these tradeoffs, which has several real-world implications. While past studies have demonstrated that imagining the future leads to more patient choices, the studies in my thesis are the first to investigate the relationship between imagination as an individual difference variable and discounting. This thesis furthers the understanding of components underlying imagination (Chapter 2), how these neural components are engaged in choices about the future (Chapter 3), and behavioral manipulations aimed at changing discounting behavior through targeting one of these components (Chapter 4). In Chapter 2, we examine the underlying processes of imagining the future. We independently manipulated vividness and valence to tax the constructive and evaluative aspects of imagination, and find vividness- and valence-specific regions in distinct areas of the default mode network. Chapter 3 extends these findings to investigate how these regions are activated when participants make choices about the future. We find greater engagement of the constructive network for chosen than unchosen delayed rewards, suggesting that promoting imagination at the single choice level makes patience more likely. However, this difference is most robust for high discounters, suggesting that high discounters are more likely to rely on vividness or tangibility as a determinant of choice. Therefore, enhancing visualization abilities might in fact lead to more impulsive behavior. Chapter 4 specifically demonstrates a strong association with visualization abilities and impulsive behavior. Additionally, training individuals to visualize future goals leads to increased discounting, perhaps implying a role for the evaluative process of imagination in influencing choices towards more patient behavior.

We hypothesized there to be at least two components of imagination – construction and evaluation. Imagining a novel event in the future involves both combining elements from the past to construct a novel event (scene construction), and evaluating the affective attributes of the
imagined event (evaluation) (Addis et al., 2007, Sharot et al., 2007, Benoit et al., 2011). While
neuroimaging studies have examined neural correlates of these processes in isolation, Chapter 2
is the first to simultaneously manipulate both the constructive and evaluative components of
imagination and show separate modifiability within the regions activated for scene construction
and evaluation (Sternberg et al., 2001). This dissociation helps us better understand the
psychological processes of imagination and expand on previous work investigating activity in the
DMN. Previous literature demonstrates that the DMN as a whole is engaged during imagination,
previously thought to be a single process (Botzung et al., 2008; Hassabis et al., 2007; Hassabis &
Maguire, 2007). However, our results suggest a specialization within the DMN with respect to
function where one set of regions (ventral/MTL subsystem) is involved in construction and
another set of regions (dorsal/core subsystem) is involved in evaluation of imagined events.
Knowing that imagination can be composed of two distinct components that can be manipulated
by changing the vividness and valence respectively can pave the way for future intervention
studies that investigate how imagining future outcomes may lead to more patient behavior that
use this understanding. For example, with regard to the finding that imagining the future at the
time of choice reduces discounting, these manipulations could be more precisely tailored to tax
only the evaluative or constructive components to see if isolating one or the other has stronger
effects on discounting. rather than training a high discounter to be a better visualizer, perhaps
training them to think more abstractly about the future would lead to the desired effects.

Chapters 3 and 4 extend the results from Chapter 2 and examine imagination within a
decision-making context. Chapter 3 reveals that both the constructive and evaluative networks
are engaged when people make decisions about the future, specifically when choosing delayed
options. While increased activity in valence-specific regions is consistent with prior work on
positive imagination and value-based decision making (Sharot et al., 2007, Kable & Glimcher,
2007), the engagement of vividness-specific regions demonstrates a role for tangibility in
intertemporal choice that is distinct from value, and supports the idea that tangibility influences choices about delayed outcomes.

Additionally, our results reveal individual differences in the extent to which these networks are engaged during intertemporal choice. We find that the constructive network is enhanced when choosing delayed rewards more for high discounters than for low discounters. This suggests that while imagining the future more vividly may lead one to choose the delayed option more, perhaps this might be a trait-dependent effect. Enhancing everyone’s visualization abilities in general may not lead to more patient behavior since these signals are stronger for high discounters. Making choices based on tangibility might in fact be a feature of those who discount more steeply, so enhancing imagination in general may lead to more impulsive decision-making.

However, a confound in Chapter 3 is that higher discounters are also likely to choose a fewer number of delayed options, and delayed options that are chosen may be associated with less delay. Therefore, it is important to gather converging evidence in Chapter 4. Chapter 4 examined the behavioral relationship between construction or vividness and discounting, and we found that greater visualization abilities were associated with steeper discounting. Additionally, when participants were trained to become better visualizers, this changed preferences to shift towards more impulsive behavior. Individual differences in the ability to visualize as measured by the Vividness of Visual Imagery Questionnaire (VVIQ) were associated with discount rates, while lower VVIQ scores, indicating better visualization abilities were correlated with higher discount rates.

While some studies found the opposite relationship with imagination and discounting, there could be several reasons. Methodologically, the prior studies mainly examined the state effects of imagination on discounting, while Chapter 4 investigates trait-level differences. Another is the type and length of manipulation used. Often, only a single manipulation of imagination was administered before making a choice (Peters & Buchel, 2010; Benoit et al., 2011). Chapter 4 is the first to examine the long-term effects of imagination on decision-making. However, we found
that repeatedly imagining future goals led to more impulsive behavior. This seems to support the findings extended by Malkoc and Zauberman about concrete mindset and present bias. Perhaps repeatedly imagining the future made the future less abstract and more concrete, which may actually lead to greater impulsivity (Malkoc and Zauberman, 2010). Our results demonstrate that repeated imagination may in fact, not be beneficial to generate more patient behavior, perhaps due to the incorporation of personal goals in our study. While it is possible that imagining future events related to personal goals (as manipulated in Study 3) may make them appear subjectively closer in time, imagining obstacles required to achieve them may actually enhance preference for the immediate option (Snider et al., 2016).

Another reason why imagining the future may lead to greater discounting could be if the future is deemed bleak or uncertain (Lempert et al., 2012; Bulley et al., 2016). This has implications for public policy, as campaigns targeted at reducing risky behavior such as smoking may not want to highlight the risk of early death. In fact, making mortality more salient leads to more impulsive discounting (Kruger et al., 2008; Pepper & Nettle, 2013, 2014). However, in older adults, there is evidence that discounting actually decreases with age (Green et al., 1994). Older adults tend to be more patient (Green et al., 1994), and they also exhibit greater impairments in episodic future thinking (Schacter et al., 2007, Addis et al., 2008; Levine et al., 2002). This further lends itself to suggest that perhaps being a vivid imaginer is not a trait conducive to acting in a patient manner. Vividly imagining the future may enhance vivid imagination of the present, and while good outcomes may be emphasized, it is also likely for bad outcomes to be greatly visualized, thus leading to more impatient behavior.

Future analyses of interest can apply multivariate pattern analysis to determine whether neural activity in vividness-specific regions predicts future choices within an individual. Given that high discounters engage vividness-specific regions to a greater extent, one might predict that the degree to which we can predict future choice based on activity patterns in the vividness regions might also be greater for high discounters compared to low discounters.
Our results demonstrating that enhancing vividness leads to more impulsive behavior suggest an alternate interpretation of how imagination might affect decision-making. Benoit et al. (2011) found that it was emotionality that was effective in reducing discounting. Thus, prior studies may have found imagining the future led to more patient behavior not because they engaged the constructive imagination component, but rather because they were positive and enhanced the affective response. A future line of research would be to trying to independently manipulate the valence and vividness of the imagined choice during discounting. In studies where imagination led to more patient behavior, participants imagined positive, personally relevant scenarios, often related to the reward or day of reward delivery (Benoit et al., 2011; Peters and Buchel, 2010). However, another line of research indicates equally vivid negative events, worry about an upcoming stressful event, or uncertainty about the future all lead to more impulsive decision-making (Bulley et al., 2016, Liu et al., 2013). Liu and colleagues (2013) found that imagining positive events reduce discounting, while imagining negative events increase discounting. We conducted a pilot study to determine if evaluation was the key factor, and found a trending relationship between valence and discounting. Participants had lower discount rates when imagining positive scenarios relative to imagining negative scenarios (t(34) = 1.73, p = 0.09) or no imagination at all (t(34) = 1.68, p = 0.10). We also examined the effects of gratitude, a more specific positive emotion, since a previous study found a relationship where recalling a grateful event leads to reduced impatience (DeSteno et al., 2014). Similarly, we found that writing about a person one is grateful for led to more patient behavior than writing about a typical day (t(33) = 1.74, p = 0.09). Since discount rates are usually a relatively stable measure (Senecal et al., 2012, Ohmura et al., 2006, Kirby, 2009), using another task such as preference judgments might be a more sensitive way to detect subtle changes when manipulating specific emotions.

While this thesis has focused on healthy individuals, an important future direction would be to look at the relationship between imagination and discounting in other clinical populations. While a few studies have looked at obese subjects and alcohol-dependents (Daniel et al., 2013,
Snider et al., 2016, Elton et al., 2017), it remains to be seen whether different populations may be affected differentially by the imagination manipulation. This would particularly be important, as shifting individuals engaging in maladaptive behavior such as gambling or drug abuse towards more advantageous decisions could have beneficial societal implications.

However, there are also situations where immediacy might in fact be more adaptive. If there is a situation where mortality risk is high or the future is uncertain, it is better to be more impatient (Bulley et al., 2016). In addition, if promised rewards are withheld or of low quality, taking the immediate reward may be more beneficial. In addition, in areas that involve capitalizing on opportunities such as entrepreneurship, having a more impulsive mindset can lead to greater success.

In light of the results from the three studies presented here, important considerations will need to be made regarding future interventions to reduce discounting behavior. Importantly, different mechanisms may work better on certain individuals. Enhancing vividness in individuals who are already steep discounters may lead to greater impulsive behavior. Perhaps increasing vividness of only the future option, or emphasizing the positive future outcome while downplaying vividness might be more beneficial for high discounters. In addition, there may be other individual traits that confound discounting that would affect the best strategy used to elicit patient behavior. Maybe specific positive affect is a target, but further research will need to be done regarding the brain areas engaged and how it might influence choice. Manipulating certainty of a planned versus unplanned positive future event is also a possibility, since previous work using imagination to reduce discount rates has mostly used planned future events (Benoit et al., 2011; Peters & Buchel, 2010). Additionally, because discounting is a fairly stable trait, achieving long-lasting effects may require more intensive, multimodal, individually tailored interventions. It will be important to perform future experiments isolating components of imagination to discover what might play an active role in increasing patience, as well as the brain networks involved to make advantageous future decisions.
Conclusions

The research described here focused on the underlying components of imagination and its influence on value-based decision-making. We found that imagination consists of a constructive and evaluative component, and these processes are differentially represented in the default mode network. In the context of intertemporal choice, choosing a delayed option results in activation of the constructive component, suggesting chosen delayed outcomes may be viewed as more tangible, and this modulation is seen to a greater extent in high discounters. Behaviorally, taxing the constructive component leads to more impatient decision-making. While we have furthered the understanding of how components of imagination are represented in the brain and its effects on choice, further investigation is needed to examine the interaction between constructive and evaluative regions during choice behavior. Investigating connectivity between these regions, examining brain activity patterns within individuals, or manipulating the evaluative component in a more specific manner may be useful in determining a more long-lasting intervention to reduce risky behavior.
Visualization Group: Goal Oriented Visualization

First Scenario

Take a moment to get comfortable and well supported in your seat. Become aware of all the many parts of your body that are touching your seat and touching the floor. Gently close your eyes. Allow yourself to take up space and feel safe. (Pause)

Sit in an upright and relaxed posture, allowing each part of your body to feel connected. Attune to the breath as it moves in and out of your body. Feel supported by the earth underneath you.

(Sound of singing bowl)

Begin to become aware of the rise of your belly as you breathe in and then notice as it settles back down as you breathe out. Bring your attention to the movement of the breath and the belly, allowing that to be your focus. There will be many times that your mind will wander, and you will begin to have conversations with yourself. When you notice this happening, very kindly and without any judgment, become aware of your thoughts or feelings and then let them go or let them be, and come back to the belly and the breath over and over again. This process is very natural and will happen many times during this guided meditation.

As you are breathing in and out, imagine that you are sending the warmth of your breath to any place in your body that is tense, tight or uncomfortable. Allow the warmth of the breath to loosen and relax all of the parts of your body from the top of your head, to the bottoms of your feet. (Pause) As you exhale, you may become more at ease and wish to release tension from your body.

The sound of my voice now will guide you into imagining a place where you can be safe, and comfortable, visualizing a goal that you would like to achieve.

Imagine you are sitting on a bench by yourself in a very peaceful spot. No one is around. You notice: there is a small blue bottle on the bench, immediately to your left. You are enjoying the day, and take in the quiet. It soothes you.
Now take a moment, and identify a goal that is important to you, a goal that you have not yet achieved, but that you truly desire. (Pause) See if you can visualize this goal that you have for yourself. (Pause) Breathe deeply and let the sensation of the goal move slowly through your body; from the top of your head to the bottom of your feet. Allow yourself to experience the goal in your body and in your mind. (Pause)

Now that you have identified this important goal, begin to think about the main obstacle that currently prevents you from reaching the goal. (Pause) Envision the obstacle, and notice how your body feels when you think about it. What emotions, if any, does envisioning this goal bring up for you? (Pause)

Imagine the obstacle as having a specific color, and a specific shape. (Pause) Take your time... You might want to enlarge the obstacle and make its color even brighter. (Pause) Now pick up the blue bottle. You will notice that the liquid inside the bottle has a silver color. There are instructions on the label. They read: Place three drops on your obstacle, say goodbye, and then watch your obstacle shrink and disappear. (Pause)

You are now ready to address your obstacle. Pick up the bottle. Take out the dropper, place it above your obstacle, and squeeze the rubber tip...one drop falls on the obstacle, then a second, then a third.

Now say goodbye to the obstacle, as you close the bottle and set it down. (Pause) You may even notice some emotions connected to bidding farewell to that one significant thing that has prevented you from achieving your goal.

You hear a fizzing sound, as the drops hit the obstacle. As you watch, the obstacle slowly begins to shrink in size. Now it is three-quarters of its original size, now only a half, now a quarter, now you can hardly see it, as it totally disappears, and there is nothing there. (Pause) The obstacle to your goal has completely disappeared. Really take that in. (Pause) How do you feel? (Pause)
Imagine now that you are waking up to a new morning without the obstacle. What is your first thought? (Pause) How are you feeling? (Pause)

You get up from your bed, and begin your day. You are now free to pursue your desired goal. How long do you think it might take to reach that goal, now that your main obstacle has disappeared? Will it take you a few days? (Pause) Will it take you a few months? Will it take you a few years to accomplish your goal? (Pause)

With your next breaths, the time needed to achieve your goal magically passes. (Pause)

Now imagine that you have achieved your goal, and you awaken on a typical morning. How does it feel to open your eyes to your life with this goal achieved? (Pause)

Now that your goal has been reached, think about how your life has been affected. (Pause) What do you see that lets you know that you have achieved your goal? (Pause) What do you hear? (Pause) What do you feel that lets you know that you have achieved your goal?

Imagine a particular time and place where you stand, having achieved your goal. Where is that scene located? (Pause)

In that scene, you look out through your own eyes …what do you see? Focus on the scene…what colors, do you see? (Pause) What shapes? (Pause) Sharpen your focus. What is immediately in front of you? (Pause) What is in the distance? (Pause)

When you think of yourself, and what you have achieved, what do you feel? (Pause)

Dwell for a moment in that feeling, really take it in. (Pause) Now what words might you say to yourself to congratulate your hard work and perseverance? (Pause)

Imagine that you are telling a friend of your accomplishment. (Pause) How does that person react to the news? (Pause) What words do they use to congratulate you? (Pause)

Now imagine even more time has passed since you have achieved your goal. How does it feel to be in the future with your goal completed more than six months ago? (Pause) Do you feel any difference in your body…in your mind? (Pause) Do you notice a different sense of confidence in yourself? (Pause)
As you look back, with your goal achieved so many months ago, you recall the main obstacle that once prevented you from achieving your goal. From this vantage point, how does this obstacle appear to you now? (Pause)

In a few moments, after you hear the sound of the singing bowl, you can slowly open your eyes. When you do, you will feel refreshed, and ready to pursue your goal. (Pause) (Sound of the singing bowl). May you continue to pursue your goals, feeling supported and optimistic.

Second Scenario

Take a moment to get comfortable and well supported in your seat. Become aware of all the many parts of your body that are touching your seat and touching the floor. Gently close your eyes. Allow yourself to take up space and feel safe. (Pause)

Sit in an upright and relaxed posture, allowing each part of your body to feel connected. Attune to the breath as it moves in and out of your body. Feel supported by the earth underneath you. (Sound of singing bowl)

Begin to become aware of the rise of your belly as you breathe in and then notice as it settles back down as you breathe out. Bring your attention to the movement of the breath and the belly, allowing that to be your focus. There will be many times that your mind will wander, and you will begin to have conversations with yourself. When you notice this happening, very kindly and without any judgment, become aware of your thoughts or feelings and then let them go or let them be, and come back to the belly and the breath over and over again. This process is very natural and will happen many times during this guided meditation.

As you are breathing in and out, imagine that you are sending the warmth of your breath to any place in your body that is tense, tight or uncomfortable. Allow the warmth of the breath to loosen and relax all of the parts of your body from the top of your head, to the bottoms of your feet. (Pause) As you exhale, you may become more at ease and wish to release tension from your body.
The sound of my voice will now guide you into imagining a place where you can be safe, and comfortable, visualizing a goal that you would like to achieve.

It is morning, and you have just taken a seat in front of your computer. You push the “on” key, and you hear the familiar sound of the computer booting up.

You are watching the monitor, as the computer goes through its usual processes. The sign-in page appears on your screen. At first glance, nothing seems unusual. You see that your cursor is blinking in the space labeled “username,” and you type in your last name, as you always do.

You then move the cursor to the space immediately below, and prepare to type in your password.

However, to your surprise, the space that usually reads “password” now requests something different. It reads: “Name your goal.”

Now take a moment, and identify another goal that is important to you, one that is different than the goal that you identified in the first visualization. (Pause) See if you can visualize this new goal that you have for yourself. (Pause) Breathe deeply and let the sensation of the goal move slowly through your body; from the top of your head to the bottom of your feet. Allow yourself to experience the goal in your body and in your mind. (Pause)

Once you have identified and experienced this new goal, imagine that you are typing a brief description of this goal, in the space provided. (Pause) Now imagine that you hit the “enter” key.

After you hit the “enter” key, another space appears, with the following request: “Name your greatest obstacle to achieving this goal.’

Now take a moment to identify the main obstacle that currently prevents you from reaching the goal. Envision the obstacle; what is it? (Pause) Notice how your body feels when you think about it. (Pause) What emotions, if any, does envisioning this obstacle bring up for you? (Pause)
Now imagine typing into the space a brief description of your most important obstacle to achieving your goal. (Pause) You again hit the “enter” key, and now a picture of that greatest obstacle appears on the screen before you. What do you see? (Pause) Imagine the obstacle as having a specific color, and a specific shape. Take your time. (Pause) Allow your eyes to scan the picture of your greatest obstacle and notice its detail. (Pause) It is now time to confront this obstacle. You move your cursor to the center of the screen, so it is directly on top of the obstacle. You then hit the “delete” key on your keyboard. Immediately, on your screen, there appears a message that reads: “You are about to permanently delete your greatest obstacle. Are you sure?” You think for a moment, and then you select “Yes,” and you click your mouse. (Pause) There then appears on your screen a small red bar, which tracks the deleting of your obstacle. You watch as the red bar slowly extends. Your obstacle is 25% deleted; now the bar moves a bit more…it is 50% deleted….now 80%...and now 100%. (Pause) Say goodbye to your obstacle, as a new message appears on the screen. It reads: “Your obstacle has been permanently deleted.” (Pause) The obstacle to achieving your goal is gone from your life. Really take that in. (Pause) You may even notice some emotions connected to bidding farewell to that one significant thing that has prevented you from achieving your goal. (Pause) Imagine now that you are beginning your day, without the obstacle holding you back. What are your thoughts? (Pause) How are you feeling? (Pause) You are now free to pursue your desired goal. How long do you think it might take to reach that goal, now that your main obstacle is no longer there? Will it take you a few days? (Pause) Will it take you a few months? Will it take you a few years to accomplish your goal? (Pause) With your next breaths, the time needed to achieve your goal magically passes. (Pause) Now imagine that you have achieved your goal, and you awaken on a typical morning. How does it feel to open your eyes to your life with this goal achieved? (Pause)
Now that your goal has been reached, think about how your life has been affected.

(Pause) What do you see that lets you know that you have achieved your goal? (Pause) What do you hear? (Pause) What do you feel that lets you know that you have achieved your goal? Imagine a particular time and place where you stand, having achieved your goal. Where is that scene located? (Pause) In that scene, you look out through your own eyes … what do you see? Focus on the scene … what colors, do you see? (Pause) What shapes? (Pause) Sharpen your focus. What is immediately in front of you? (Pause) What is in the distance? (Pause) When you think of yourself and what you have achieved, what do you feel? (Pause) Dwell a moment in that feeling, really take it in. (Pause) Now what words might you say to yourself to congratulate your hard work and perseverance? (Pause)

Imagine that you are telling a friend of your accomplishment. How does that person react to the news? (Pause) What words do they use to congratulate you? (Pause)

Now imagine even more time has passed since you have achieved your goal. How does it feel to be in the future with your goal completed more than six months ago? (Pause) Do you feel any difference in your body… in your mind? (Pause) Do you notice a different sense of confidence in yourself? (Pause) As you look back, with your goal achieved so many months ago, you recall the main obstacle that once prevented you from achieving your goal. From this vantage point, how does this obstacle appear to you now? (Pause)

In a few moments, after you hear the sound of the singing bowl, you can open your eyes. When you do, you will feel refreshed, and ready to pursue your goal. (Pause) (Sound of the singing bowl) May you continue to pursue your goals, feeling supported and optimistic.

Control Group: Relaxation Meditation

First Scenario

Take a moment to get comfortable and well supported in your seat. Become aware of all the many parts of your body that are touching your seat and touching the floor.
Gently close your eyes. Allow yourself to take up space and feel safe. (Pause)

Sit in an upright and relaxed posture, allowing each part of your body to feel connected. Attune to the breath as it moves in and out of your body. Feel supported by the earth underneath you.

(Sound of singing bowl)

Begin to become aware of the rise of your belly as you breathe in and then notice as it settles back down as you breathe out. Bring your attention to the movement of the breath and the belly, allowing that to be your focus. There will be many times that your mind will wander, and you will begin to have conversations with yourself. When you notice this happening, very kindly and without any judgment, become aware of your thoughts or feelings and then let them go or let them be, and come back to the belly and the breath over and over again. This process is very natural and will happen many times during this guided meditation.

Inhale fully and deeply...and release the breath slowly. Feel the sensation of letting go.

(Pause) Inhale fully again, and exhale slowly. (Pause) One more time, inhale deeply and exhale slowly, feeling the sensation of letting go. (Pause) Now, allow the breath to go back to its natural rhythm. (Pause) Gently observe the breath, flowing in and out. (Pause)

You may begin to become aware of how observing the breath can bring you back to the present moment. Allow the awareness of your breath to move through your body. (Pause) Now, gently scan the various parts of your body. Are there areas that feel relaxed and at ease? (Pause) Are there any particular areas that feel tense, tight or uncomfortable? (Pause) Allow a gentle awareness to touch and relax those areas. (Pause)

Now bring your attention to the top of your head...then moving to the forehead, soften and relax from the inside out. (Pause) Move the warm energy of the breath to the eyebrows and then the eyes. (Pause) Imagine the eyes resting and feeling refreshed. (Pause) Now, using your mind and your breath, move down the face and soften the cheeks...the nose...and the jaw. (Pause) The jaw is a place in the body that you might hold emotions, tension or discomfort.
Now, see if you can bring a slight smile to your face. A smile relaxes the muscles in the face and sends a message to the whole nervous system to relax and feel more at ease. (Pause) Continue to observe the breath. (Pause)

If you notice that the mind has drifted into thought….that's perfectly natural. Just pause and notice where the mind has gone. Bring your attention to that place, acknowledge the thoughts, the emotions, or sensations, and then let them go, or let them be, and return to the breath. (Pause)

Now, move your attention to the neck. (Pause) Allow the breath to loosen the shoulders. (Pause) Follow the shoulders…down to the elbows…the elbows to the wrist…and open the palms. (Pause) Feel the sensation of an open and relaxed palm. (Pause) Rest in the present moment. (Pause)

Now using your breath and your attention, feel the chest and the back opening horizontally and vertically, creating space for the heart. (Pause) Allow the heart to open from the inside out. (Pause)

Now move your attention to the belly. Notice its rise, as you breathe in, and its fall, as you breathe out. (Pause) Feel the belly relax with each rise and fall. (Pause) Let the belly soften deep into the torso. (Pause)

Allow the body to be a safe place, a place where you feel at home. (Pause) Now allow the warmth of your breath to move down the legs, touching your knees, your ankles, and then moving all the way down to your toes. (Pause) Feel the tension in the body being released through the soles of your feet. (Pause) Enjoy the feeling of letting go, and relaxing into your body. (Pause)

Imagine the softness of your breath infusing the body as a whole, from the top of your head to the soles of your feet. (Pause) The breath is now able to flow freely throughout the body. There may still be places in the body where tension or discomfort resides …that's fine, let it be as it is. (Pause)
Now take note of what you are experiencing in your body and your mind. (Pause) If you are feeling more at ease, see if you can return to this feeling, as you go through your day, if only for a few breaths. (Pause)

Continue to follow your breath until you hear the sound of the singing bowl. (Pause)

(Sound of singing bowl)

Follow the sound as it fades. (Pause) When you feel ready, slowly open your eyes. (Pause) Without judgment, just notice how you are feeling. (Pause) Thank yourself for taking the time to relax in the present moment.

Second Scenario

Take a moment to get comfortable and well supported in your seat. Become aware of all the many parts of your body that are touching your seat and touching the floor. Gently close your eyes. Allow yourself to take up space and feel safe. (Pause)

Sit in an upright and relaxed posture, allowing each part of your body to feel connected. Attune to the breath as it moves in and out of your body. Feel supported by the earth underneath you. (Sound of singing bowl)

Begin to become aware of the rise of your belly as you breathe in and then notice as it settles back down as you breathe out. Bring your attention to the movement of the breath and the belly, allowing that to be your focus. There will be many times that your mind will wander, and you will begin to have conversations with yourself. When you notice this happening, very kindly and without any judgment, become aware of your thoughts or feelings and then let them go or let them be, and come back to the belly and the breath over and over again. This process is very natural and will happen many times during this guided meditation.

As you breathe in, imagine that you are sending the warmth of your in-breath to any place in your body that is tense, tight or uncomfortable. (Pause) Allow the warmth of the in-breath to loosen and relax all of the parts of your body from the top of your head, to the bottoms of your feet. (Pause)
Now, focus for a moment on your out-breath. (Pause) As you exhale, you may become more at ease and wish to release tension from your body. (Pause) Now, continue in a comfortable, upright and alert posture. Enjoy your breathing…in and out…allowing yourself an opportunity to arrive in the present moment. (Pause) Allow your arms to rest in your lap. (Pause) Allow your hands to connect with each other. (Pause) As each moment unfolds, allow a feeling of love to fill your heart… (Pause) …love toward yourself…and love toward all beings. (Pause)

As you continue the awareness of your breath you might begin to notice particularly its rhythm…Inhaling…exhaling. (Pause) Experience the vibration created by the breath, its quality and sound. (Pause)

Greet the in-breath and the out-breath with appreciation. (Pause) Now notice the transition between the breathing in and breathing out. (Pause) Perhaps notice a pause between the in-breath and the out-breath, like a comma between words of a sentence. (Pause) Cultivate a kindly awareness of the present moment. (Pause)

If you find your mind wandering, gently notice where it is right now. (Pause) Perhaps it is focusing on what has already passed. (Pause) Or perhaps it is focusing on what has yet to be. (Pause) Gently return to the present moment by using the movements of your breath to help ground you. (Pause)

Softly smile and notice how that feels to you. (Pause) Smiling and breathing brings a reassurance that everything is ok as it is. (Pause)

Connect with your experience…moment by moment…by moment…keeping company with yourself in the present. (Pause) Notice again the pause between the in-breath and the out-breath… notice the silence of that pause. (Pause)

Observe what is happening in the body: what physical sensation are arising and passing? (Pause) Experience the movements of your breathing, sensations of the air being moved into the body and released. (Pause) Notice as your body fills as you breathe in, taking in
nourishment for all the cells in your body. (Pause) Now, notice as the body empties as you breathe out, a sense of letting go, relaxing. (Pause). Cultivate a sense of acceptance for whatever arises. (Pause)

Notice how breathing takes care of itself. Sit on the sidelines and just let your breathing happen. (Pause) There is nowhere for you to go, and nothing to do. (Pause)

Now, as you breathe, you may feel compassion and acceptance for whatever you are experiencing in this moment. (Pause) Feel compassion and acceptance for any thoughts, feelings, or emotions that are present in this moment. (Pause)

As you go through your day, use your breath to bring you back to the present, to bring you back to a feeling of love and compassion for yourself and others. (Pause)

Thank yourself for taking this time to let go and be more in the present moment. (Pause)

Now, follow the sound of the singing bowl until it disappears. (Sound of singing bowl)

When you are ready, slowly open your eyes, and take time to bring yourself back to this room. (Pause). As you go through your day, let each breath remind you of this meditation.
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