

Dissociable Contributions of Imagination and Willpower to the Malleability of Human Patience



Adrianna C. Jenkins and Ming Hsu

Helen Wills Neuroscience Institute and Haas School of Business, University of California, Berkeley

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Abstract

The ability to exercise patience is important for human functioning. Although it is known that patience can be promoted by using top-down control, or willpower, to override impatient impulses, patience is also malleable—in particular, susceptible to framing effects—in ways that are difficult to explain using willpower alone. So far, the mechanisms underlying framing effects on patience have been elusive. We investigated the role of imagination in these effects. In a behavioral experiment (Experiment 1), a classic framing manipulation (sequence framing) increased self-reported and independently coded imagination during intertemporal choice. In an investigation of neural responses during decision making (Experiment 2), sequence framing increased the extent to which patience was related to activation in brain regions associated with imagination, relative to activation in regions associated with willpower, and increased functional connectivity of brain regions associated with imagination, but not willpower, relative to regions associated with valuation. Our results suggest that sequence framing can increase the role of imagination in decision making without increasing the exertion of willpower.

Keywords

prospection, episodic memory, decision making, impulsivity, neuroimaging, open data, open materials

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Humans often make trade-offs between immediate temptations and future payoffs. Hitting the snooze button on the alarm clock might mean skipping breakfast, and putting money into savings might mean paying future medical bills with ease. Such decisions with delayed outcomes—intertemporal decisions—pervade human life, and people who tend to forgo immediate temptations and choose more patiently in those decisions also tend to enjoy greater physical (Graziano, Calkins, & Keane, 2010), psychological (Crews & Boettiger, 2009), and financial (Gathergood, 2012) well-being.

Although patience varies from one person to the next, it also varies from one decision to the next (Lempert & Phelps, 2016). Intertemporal choices can be influenced by slight changes in how outcomes are presented, even without changes to the outcomes themselves (Loewenstein & Prelec, 1993; Magen, Dweck, & Gross, 2008; Radu, Yi, Bickel, Gross, & McClure, 2011; Thaler, 1981; Weber et al., 2007). For example, the willingness to wait for a later, greater monetary outcome can be affected by

whether the possible outcomes are presented as round numbers or decimals (Fassbender et al., 2014), and the willingness to wait an extra month for a desired experience can be affected by whether it is presented as an independent event (e.g., dinner at a fancy restaurant in 2 months) or as part of an apparent sequence (e.g., dinner at home in 1 month, dinner at a fancy restaurant in 2 months; Loewenstein & Prelec, 1993). Such effects are known as time-framing effects.

In the studies reported here, we investigated the cognitive processes underlying time-framing effects. Although the existence of such effects points to the possibility of

Corresponding Authors:

Adrianna C. Jenkins, 2220 Piedmont Ave., University of California, Berkeley, Berkeley, CA 94720
E-mail: adrianna.jenkins@berkeley.edu

Ming Hsu, Helen Wills Neuroscience Institute and Haas School of Business, University of California, Berkeley, Berkeley, CA 94720
E-mail: mhhsu@haas.berkeley.edu

intervening on choices to promote patient behavior, the feasibility of intervention is limited by the absence of a unifying explanation of the underlying mechanisms. Across research in psychology and economics, a variety of explanations for time-framing effects have been proposed. For example, it has been suggested that they result from shifts in reference points (Loewenstein, 1988) or temporal focus (Lebreton et al., 2013; Lin, Horner, Bisby, & Burgess, 2015) or changes in how outcomes are valued (Magen, Kim, Dweck, Gross, & McClure, 2014). However, the cognitive processes that give rise to these changes remain elusive (Lempert & Phelps, 2016).

One set of processes known to be important for patience supports the exertion of willpower (Hayashi, Ko, Strafella, & Dagher, 2013; MacDonald, Cohen, Stenger, & Carter, 2000). Often equated with cognitive control, willpower in the context of intertemporal choice refers to the exertion of control over an impulse to pursue an immediate temptation (Magen et al., 2014). For example, willpower might enable a sleepy student to rise for breakfast rather than succumbing to the temptation to doze off, or it might enable an excited preschooler to wait for two marshmallows rather than gobbling up an immediately available one (Shoda, Mischel, & Peake, 1990). In neuroimaging studies, the exertion of willpower is associated with activity in the dorsolateral prefrontal cortex (dlPFC) and dorsal anterior cingulate cortex (dACC), which is consistent with these regions' role in cognitive control more generally (Figner et al., 2010; Hare, Hakimi, & Rangel, 2014; McClure, Laibson, Loewenstein, & Cohen, 2004). Still, it has been difficult to explain framing effects using willpower alone. In a recent study, for example, reframing choices as sequences of events promoted patience without appearing to increase the exertion of willpower (Magen et al., 2014).

We investigated the possibility that, rather than affecting the exertion of willpower, certain ways of framing intertemporal choices increase the contribution of imagination to decision making (Berns, Laibson, & Loewenstein, 2007; Bulley, Henry, & Suddendorf, 2016). In particular, certain framings may prompt decision makers to imagine the outcomes more vividly or to imagine consequences of their choices that would not otherwise be salient (Bulley et al., 2016), thereby influencing the values associated with the choice options (Benoit, Gilbert, & Burgess, 2011; Magen et al., 2014; Peters & Büchel, 2010). Given that distant future outcomes tend to be imagined less vividly and valued less strongly than proximate ones (D'Armenbeau, Xue, Lu, Van der Linden, & Bechara, 2008), it may be possible that certain ways of framing choices guard against this decay of imagination across time and thereby boost the weight placed on of later outcomes relative to sooner outcomes. For example, getting out of bed instead of dozing might be facilitated by

imagining how energized one would feel if one had breakfast or how harried one would feel if it were necessary to skip breakfast.

Although imagination's role in framing effects is unknown, there has been growing support for the possibility that imagination can promote patient behavior more generally. Neuroimaging and lesion studies have identified brain regions consistently associated with imagination—also known as episodic simulation (Schacter, Addis, & Buckner, 2007), self-projection (Buckner & Carroll, 2007), prospection (Gilbert & Wilson, 2007), and episodic future thinking (Atance & O'Neill, 2001). These regions include the medial prefrontal cortex (mPFC), the posterior cingulate (PC) centering on retrosplenial cortex, and the hippocampus (Benoit & Schacter, 2015; Buckner & Carroll, 2007; Hassabis & Maguire, 2009; Schacter et al., 2007; Spreng, Mar, & Kim, 2009; Vann, Aggleton, & Maguire, 2009). In turn, studies have implicated these regions in hypothetical value representation (Lebreton et al., 2013; Lin et al., 2015), shown that their activation decreases with temporal distance (D'Armenbeau et al., 2008), and linked them to patience (Benoit et al., 2011; Cooper, Kable, Kim, & Zauberman, 2013; Ersner-Hershfield, Wimmer, & Knutson, 2009; Mitchell, Schirmer, Ames, & Gilbert, 2011; Peters & Büchel, 2010; Sasse, Peters, Büchel, & Brassens, 2015). Although studies often measure individual differences in imagination and patience using two different tasks, more direct evidence for a link between imagination and patience has come from studies that have manipulated imagination during decision making by cuing participants with autobiographical details (Peters & Büchel, 2010) or explicitly instructing them to imagine future events (Benoit et al., 2011).

Given the possibility that changes in imagination might underlie framing effects on patience, a particular question concerns the extent to which these effects also depend on willpower. Are imagination and willpower better understood as two components of a single route to patience or, instead, as dissociable routes by which patience may be achieved? According to the first account, imagination and willpower work in tandem; for example, imagination might increase the motivation to exert willpower. According to the second account, imagination can promote patience without affecting willpower, sidestepping the need to exert willpower over impulses by changing the impulses themselves. For example, when the alarm rings, imagining skipping breakfast might increase the desire to get out of bed and diminish the desire to return to sleep.

To investigate the role of imagination, relative to willpower, in intertemporal framing effects, we adopted a version of a classic framing manipulation from behavioral economics. Specifically, people tend to choose more patiently when a desirable outcome is presented in a sequence with a less desirable one than when it is

presented on its own (Loewenstein & Prelec, 1993), even when exactly the same outcomes are involved (Magen et al., 2008; Magen et al., 2014; Radu et al., 2011). For example, when participants faced a decision between receiving “\$10 today” and “\$12 in one week” (independent frame), they preferred to receive \$10 that day, but when the choice was framed as a choice between receiving “\$10 today and \$0 in one week” and receiving “\$0 today and \$12 in one week” (sequence frame), participants were more likely to prefer to receive \$12 in a week. This sequence manipulation enables a particularly clean test of the role of cognitive processes in framing effects because the outcomes are identical in the two frames, the monetary amounts can be varied to create a large number of nonredundant trials, and it is known to be viable in a within-subjects design.

In our first experiments, we replicated the effect of sequence framing on patience (Experiment 1a) and tested the hypothesis that sequence framing increases imagination (Experiment 1b). To test this hypothesis, we combined the framing manipulation with a thought-listing paradigm that included measures of vividness from studies of episodic simulation (Addis, Musicaro, Pan, & Schacter, 2010; Martin, Schacter, Corballis, & Addis, 2011). In Experiment 2, we tested the hypothesis that sequence framing increases the extent to which patience is associated with activation in imagination-related brain regions. In particular, although both imagination and willpower may be involved in patience to some degree, we investigated the possibility that sequence framing would promote the contribution of imagination, relative to willpower. To do this, we scanned participants using functional MRI (fMRI) as they made a series of choices under both independent- and sequence-framing conditions.

Experiment 1a

Method

We first attempted to replicate the sequence-framing effect. We recruited a total of 122 undergraduate participants for a behavioral experiment in which we manipulated whether choices were presented as independent events (e.g., Option A: \$8.00 the next day; Option B: \$10.00 in 7 days) or sequences (e.g., Option A: \$8.00 the next day, \$0.00 in 7 days; Option B: \$0.00 the next day, \$10.00 in 7 days) in a within-subjects design. Power analyses determined that this sample size would be sufficient to detect a medium-sized effect, typical of the intertemporal-framing literature, at 95% power, using $p < .05$. Each choice involved a given amount to be received the following day versus \$10.00 to be received after a delay. The amounts to be received the following day ranged

from \$1.00 to \$11.00 in \$1.00 increments, and the delay was 7 or 30 days. Trials on which the sooner amount was equal to or greater than the later amount were included as catch trials and discarded before analysis. On each trial, participants reported which payment option they preferred and how strongly, using a slider on a continuous scale anchored by *strongly prefer A* and *strongly prefer B*. For analysis, responses were converted to values from 0 (strong preference for the sooner, smaller amount) through 100 (strong preference for the later, greater amount, indicating patience). Participants made 22 decisions (11 for each delay) in random order.

Results

Participants expressed stronger preferences for the later, greater option in the sequence frame ($M = 75.6$) than in the independent frame ($M = 68.2$), $t(121) = 4.92$, $p < .0001$. Figures 1a and 1b show how the sequence frame affected patience across delays and amounts.

Experiment 1b

Method

To investigate the effects of sequence framing on imaginative processes, we first used a thought-listing paradigm in which participants explained how they were thinking about the decision. Independent raters subsequently coded participants' written thoughts for imaginative detail. Participants also reported how much they had imagined the outcomes. We recruited a total of 203 participants through Amazon's Mechanical Turk for this behavioral study; 104 participants were randomly assigned to consider a single intertemporal decision framed as a choice between two single outcomes (Option A: “\$100 tomorrow”; Option B: “\$120 in 30 days”), and 99 participants were randomly assigned to consider a monetarily equivalent decision framed as a choice between two sequences of outcomes (Option A: “\$100 tomorrow and \$0 in 30 days”; Option B: “\$0 tomorrow and \$120 in 30 days”). Power analyses determined that this sample size would be sufficient to detect a medium-sized effect, typical of the intertemporal-framing literature, at 95% power, using $p < .05$. Data were collected in a single batch. After viewing the options but prior to making their decision, participants were asked to “please tell us everything that you are thinking as you consider this decision” (Weber et al., 2007). They typed their thoughts in a free-response box (minimum of 40 characters, maximum of 4,000 characters; see Table 1 for examples illustrating the coding; see Table S1 in the Supplemental Material available online for a full list of responses). Participants then indicated whether

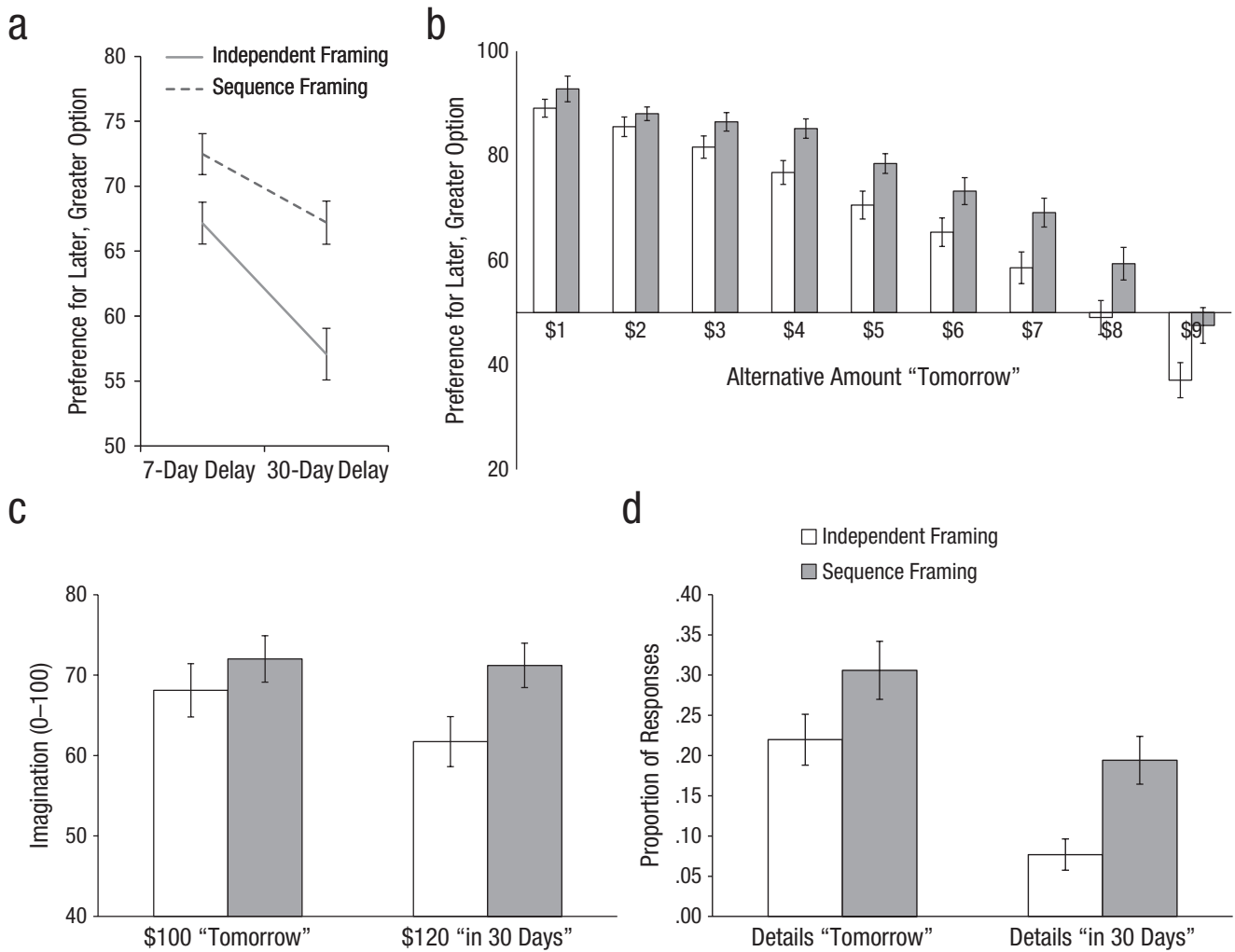


Fig. 1. Results from Experiments 1a and 1b. For Experiment 1a, the line graph (a) shows overall preference for the later, greater option (\$10) as a function of delay, separately for the independent- and sequence-framing conditions, and the bar graph (b) shows preference for the later, greater option for each combination of sooner, smaller alternative and framing condition. For Experiment 1b, the graphs show (c) mean self-reported imagination regarding the \$100 and \$120 outcomes and (d) mean proportion of free responses containing imaginative detail regarding the sooner and later options, separately for the two framing conditions. Error bars represent ± 1 SEM.

they preferred Option A or Option B (binary forced-choice format).

We collected two measures of imagination. After indicating their decisions, participants reported the degree to which they had imagined receiving \$0 the next day, receiving \$100 the next day, receiving \$0 in 30 days, and receiving \$120 in 30 days—individually and in random order, using a continuous slider bar (anchored by *did not imagine at all* and *imagined it vividly*); responses were converted to discrete values (0–100) prior to analysis. Additionally, two coders, blind to condition and hypotheses, coded each participant’s free response for the extent to which it reflected consideration of concrete details associated with the sooner and later time points, respectively (0 = no, 1 = yes). Coders’ ratings were averaged for each participant.

Results

Behavioral evidence that sequence framing increases imagination. Using both the self-report and the independent-coding measures, we found evidence that sequence framing promoted imagination. When we analyzed self-reports of imagination collapsing across all four possible choice consequences (receiving \$0 the next day, receiving \$100 the next day, receiving \$0 in 30 days, and receiving \$120 in 30 days), we found that participants in the sequence-framing condition self-reported more imagination ($M = 55.3$) than did participants in the independent-framing condition ($M = 48.1$), $t(202) = 2.39$, $p = .018$, $d = 0.34$. Moreover, this effect was robust to exclusion of the \$0 outcomes: When we restricted analysis to the \$100 and \$120 outcomes, which were

Table 1. Examples Illustrating the Coding of Participants' Free Responses in Experiment 1b

| Framing condition and coding | Free response |
|---|--|
| Independent framing | |
| Imaginative detail present for "tomorrow" only | I'd rather have the money tomorrow even if it's a lesser amount. I can get the things I need instead of waiting. I could use that money for groceries. Why wait a month for just \$20 more? |
| Imaginative detail absent for both "tomorrow" and "in 30 days" | Thinking that I have my son's birthday in a few days and I could really use that money tomorrow. He wants some \$250 shoes and that money will help toward that. I had told him that they were too expensive, but if I could get \$100 tomorrow, I will definitely be buying those shoes. How much the difference in the money is and how long the time frame between is. |
| Sequence framing | |
| Imaginative detail present for both "tomorrow" and "in 30 days" | How badly I need money now, how badly I will need money later, what the major expenses will be for me in this time period, is a \$20 difference worth the 30 day wait, and what I could buy with that extra \$20 if I wait. |
| Imaginative detail present for "in 30 days" only | I'm thinking if the extra 20 is worth waiting for, I'm thinking of the time frame. I really think that I could wait for it and it will be a nice surprise 30 days from now. It would be nice to have the 100 now, but 20 dollars at the end of the month is probably worth it because that is like one week's gas money. |

presented explicitly in both conditions, we again found that participants in the sequence-framing condition reported more imagination than did participants in the independent-framing condition (Fig. 1c), $t(202) = 2.09$, $p = .038$, $d = 0.30$. Independent coding of the free responses also showed that participants were more likely to mention concrete details in the sequence-framing condition ($M = .25$) than in the independent-framing condition ($M = .16$), $t(202) = 2.66$, $p = .009$, $d = 0.53$ (Fig. 1d).

Behavioral evidence that sequence framing minimizes imagination decay over time. Results for imagination regarding the two time points were consistent with the results of past research. Participants reported more imagination of the sooner ($M = 54.5$) than the later ($M = 49.0$) time point, $t(202) = 2.74$, $p = .007$, $d = 0.55$. Similarly, they were more likely to mention concrete details regarding the sooner ($M = .27$) than the later ($M = .14$) time point, $t(202) = 4.61$, $p < .0001$, $d = 0.92$. However, we found evidence that sequence reframing guarded against the temporal degradation of imagination. For the sooner, smaller reward, framing condition had no effect on participants' self-reported imagination ($p > .15$) or on scores for free-response detail ($p > .15$). In contrast, for the later, greater reward, participants in the sequence-framing condition self-reported significantly more imagination ($M = 71.2$) than did participants in the independent-framing condition ($M = 61.7$), $t(202) = 2.30$, $p = .023$, $d = 0.32$ (Fig. 1c). Similarly, participants were significantly more likely to mention concrete details regarding the later time point in the sequence-framing condition ($M = .19$) than in the

independent-framing condition ($M = .08$), $t(202) = 3.29$, $p = .002$, $d = 0.66$ (Fig. 1d). Although condition and time point did not have a significant interaction effect on self-reported imagination ($p > .15$), they did have a significant interaction effect on free-response detail, $F(1, 202) = 13.6$, $p < .001$, $d = 0.73$.

Imagining the later, greater reward was associated with patience. We next examined the relationship between imagining the future reward and willingness to wait for that reward. The degree to which participants imagined the later, greater outcome relative to the degree to which they imagined the sooner, smaller outcome (later – sooner) was positively associated with patience (i.e., choice of the later outcome), $r(201) = .593$, $p < .00001$. Moreover, imagination of the later, greater outcome significantly mediated the relationship between framing condition and patience (estimate = 0.13, 95% confidence interval = [0.03, 0.23], $p = .01$). Similarly, greater free-response detail regarding the later, relative to the sooner, time point was associated with greater patience, $r(201) = .230$, $p < .001$.

These results provided initial evidence that sequence framing promotes imagination, which in turn promotes patience. In particular, the use of a self-report imagination measure, along with independent coding of detail, gave us confidence that the framing manipulation indeed affected imaginative processes. Additionally, the fact that participants made their free responses prior to their decisions gave us confidence that the differences in imagination preceded the differences in choice. However, Experiment 1 was not well equipped to address questions

about the extent to which different degrees of imagination across different choices within an individual are associated with different degrees of patience, nor does it speak to the mechanisms through which imagination might affect choice behavior. In particular, it did not address the hypothesis that imagination can affect patience independently of willpower by changing value representations; fMRI is better suited to address these questions.

Experiment 2

Method

We scanned participants using fMRI while they performed two tasks in order to test the predictions that sequence framing (a) increases the contribution of brain regions associated with imagination, relative to those associated with willpower, to patient choice, and (b) increases functional connectivity of regions associated with imagination, relative to those associated with willpower, to regions associated with value processing. First, participants made a series of intertemporal choices with varying monetary outcomes in independent- and sequence-framing conditions (Fig. S1 in the Supplemental Material). Second, we defined independent functional regions of interest (ROIs) associated with imagination by having participants complete a separate task in which they imagined themselves (or another person) engaging in a variety of future activities. To the extent that sequence framing increases the role of imagination in intertemporal choice at the decision level, greater activation in regions associated with imagination should be associated with patience in the sequence-framing condition on a trial-by-trial basis (Lebreton et al., 2013). Moreover, to the extent that imagination gives rise to framing effects by affecting the valuation of choice outcomes, connectivity between regions associated with imagination and those associated with value processing should be greater in the sequence-framing condition than in the independent-framing condition. Finally, to the extent that imagination can increase patience in a way that does not depend on increases in willpower, the responses of regions associated with imagination should be dissociable from the responses of regions associated with willpower.

Participants. Forty-two adults (25 female) were recruited to participate in this experiment. One male participant was dismissed partway through the first imaging run because of excessive sleepiness, and 1 female participant's data were discarded prior to analysis because of excessive head movement. Because testing our hypotheses required comparisons of patient and impatient behavior, we also excluded data from those participants who failed to make at least five patient and five impatient choices across the experiment. Thus, our final sample

consisted of 29 participants. Sample size was determined by our past experience with fMRI research in combination with the behavioral results from Experiment 1a; we intentionally oversampled in order to retain at least 25 to 30 participants after excluding those whose fMRI data were unsuitable for analysis and those who made predominantly patient or impatient choices.

fMRI choice task. In the choice task, participants made decisions about when to receive different amounts of money. Prior to scanning, participants were informed truthfully that one decision would be chosen randomly at the end of the experiment for actual implementation. On each trial, participants viewed two payment options ("A" and "B"), each of which contained information about payoff timing and amount. On *independent-framing* trials, options A and B each represented a single amount at a single point in time (e.g., A: \$8 the next day; B: \$10 in 7 days). Each *sequence-framing* trial was equivalent to a corresponding independent-framing trial in content but was displayed as a sequence (e.g., A: \$8 the next day, \$0 in 7 days; B: \$0 the next day, \$10 in 7 days). Each choice was between a given amount the next day and a given amount after a delay. Amounts to be received after the delay were \$10, \$20, \$30, or \$40, and amounts to be received the next day ranged from 50% of the delayed amount to \$1 more than the delayed amount (trials on which the sooner amount was equal to or greater than the later amount were included as catch trials and discarded prior to analysis). Delays of 7, 14, 30, and 90 days were presented.

Using a button box, participants reported which payment option they preferred and how strongly, on a scale anchored by 1 (*strongly prefer A*) and 4 (*strongly prefer B*). A response of 1 or 2, therefore, indicated a choice of Option A, whereas a response of 3 or 4 indicated a choice of Option B. This scale also enabled us to measure strength of preference for parametric modulation purposes. Participants responded during an unconstrained response window and made a total of 256 choices across two functional runs. The intertrial interval was variable (2,000–10,000 ms). Trials were intermixed pseudorandomly such that each run included 64 independent-framing trials and 64 sequence-framing trials; within each run, the trials in each condition included 4 trials of each possible combination of time delay and delayed monetary amount. After scanning, one trial was chosen randomly by the computer for implementation, and participants were informed how much money they would receive and when they would receive it.

fMRI imagination task. To independently identify ROIs associated with imagination, we scanned participants during a separate task in which they rated how much they and another person would enjoy various

activities in the future. On each trial, participants viewed a short phrase describing an activity (e.g., “getting up early to watch the sunrise”) and used a button box held in both hands to report how likely it was that they (or the other person) would enjoy the given activity at some future time point (on the upcoming weekend, on a weekend in 4 months). The response scale ranged from 1 (*not at all*) to 4 (*very*). In previous studies comparing self judgments with judgments of other people, researchers have used the current head of state as a familiar, but not personally known, target (Cikara, Jenkins, Dufour, & Saxe, 2014; Jenkins, Macrae, & Mitchell, 2008; Jenkins & Mitchell, 2011; Kelley et al., 2002). Accordingly, we selected then-current U.S. President Barack Obama as the target of participants’ *other* judgments. Participants could make their response within a 4,000-ms window, after which the program advanced to the next judgment. Participants made a total of 80 judgments (20 per condition) across two functional runs. The intertrial interval was variable (2,000–10,000 ms).

Imaging procedure. The fMRI data (32 axial slices; 3 mm thick) were collected on a Siemens 3-T Magnetom Trio scanner across two functional runs for the choice task and two functional runs for the imagination task. High-resolution structural images were acquired using a Siemens magnetization-prepared rapid-acquisition gradient-echo (MP-RAGE) sequence. Functional images were acquired using echo-planar T2*-weighted imaging (repetition time = 2 s, echo time = 30 ms, voxel size = 3 × 3 × 3 mm, descending acquisition order) and were angled +30° with respect to the anterior commissure–posterior commissure line to minimize signal dropout in the mPFC. Pygame software for Mac (www.pygame.org) was used to display the stimuli, which were projected onto a screen at the end of the magnet bore and viewed by participants via a mirror mounted on the head coil. A pillow and cushions were placed inside the head coil to minimize head movement.

Imaging analysis. Imaging analyses of the choice-task and imagination-task data were conducted using the general linear model (GLM) implemented in SPM8 (Wellcome Department of Cognitive Neurology, London, United Kingdom) in conjunction with analysis tools developed by Wagner (2016) and in-house scripts. For each participant, we constructed a GLM in which the event-related design was modeled using a canonical hemodynamic response function, its temporal derivative, and additional task effects and covariates of no interest (a session mean, a linear trend, and six head-movement parameters). Trials were modeled as events with onsets time-locked to presentation of the choice (choice task) or target of imagination (imagination task). For parametric modulation

analyses of the choice-task data, each participant’s response (1–4) on each trial was included as a parametric modulator of that participant’s hemodynamic response. Contrast images from individual participants were then entered into a second-level analysis in which participants were treated as a random effect.

ROI analysis. Functional ROIs were defined in regions associated with willpower and regions associated with imagination. In neuroimaging studies, willpower has been associated consistently with the dlPFC, part of a network that also includes the dACC (Figner et al., 2010; Hare et al., 2014; McClure et al., 2004). Because our aim was to begin with willpower-related regions known to be involved in patience in the standard version of the intertemporal-choice task and to investigate the extent to which these regions are also involved in the reframed (sequence-framing) version of the task, we identified willpower ROIs using a whole-brain analysis of the data from the independent-framing condition only. In this analysis, choice was used as a parametric modulator. Regions emerging from this analysis (5 or more contiguous voxels at a voxel-wise threshold of $p < .001$) were the right dlPFC, left dlPFC, and dACC (Fig. 2a), which for simplicity we refer to collectively as willpower regions. Additionally, we identified a fully independent set of willpower regions through an automated meta-analysis of 428 studies on neurosynth.org. Our search term was “cognitive control,” as this was the closest indexed approximation of willpower. This analysis produced a whole-brain mask, from which we extracted parameter estimates.

We defined imagination ROIs using a whole-brain analysis of the data from the independent imagination task. Regions emerging from this analysis (5 or more contiguous voxels at a voxel-wise threshold of $p < .0001$) were the mPFC, PC centering on retrosplenial cortex, and right hippocampus extending into parahippocampal cortex (Fig. 2a). MarsBaR (<http://marsbar.sourceforge.net/>) was used to create three functional masks, one for each cluster; for simplicity, we refer to these clusters collectively as imagination regions.

It is worth noting that we do not mean to imply a one-to-one mapping between regions (or networks) and functions. Similarly, we do not wish to make a strong claim about the “network” status of either set of brain regions we studied; we simply use this term to refer to collections of brain regions that have been associated with particular sets of cognitive processes.

Functional-connectivity analysis. In order to examine the extent to which reward regions exhibited differences in functional connectivity to regions associated with imagination and willpower, we conducted a psychophysiological interaction (PPI) analysis (Friston et al., 1997) on

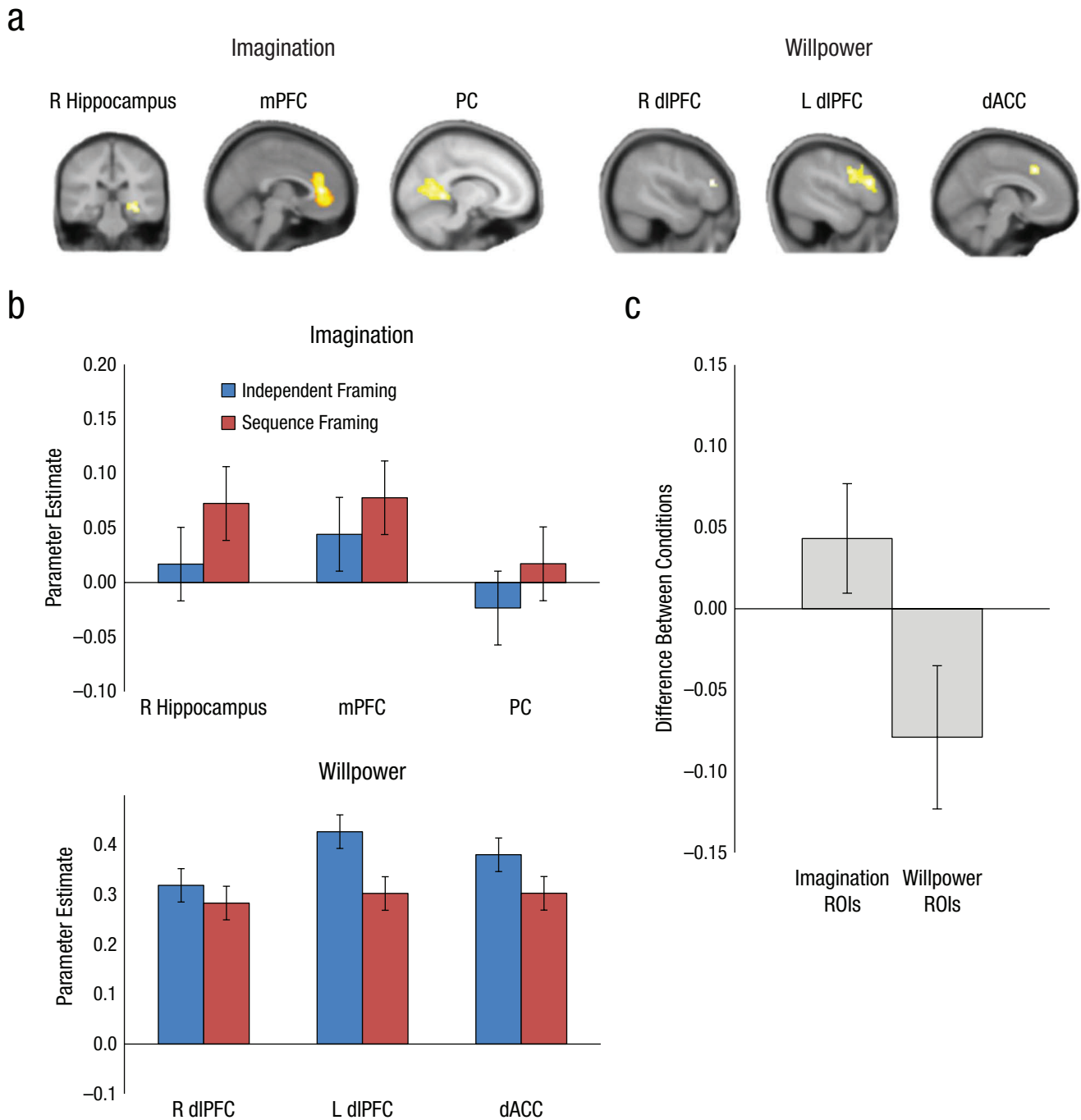


Fig. 2. Results of the region-of-interest (ROI) analyses: (a) ROIs associated with willpower and imagination, respectively; (b) mean parameter estimates (from parametric modulation analysis) of the association between patient choice and activation of the willpower and imagination ROIs in each framing condition (independent, sequence); and (c) mean difference between the parameter estimates for the two framing conditions (sequence – independent) averaged separately across the imagination ROIs and the willpower ROIs. Error bars represent ± 1 SEM. R = right; L = left; mPFC = medial prefrontal cortex; PC = posterior cingulate; dIPFC = dorsolateral prefrontal cortex; dACC = dorsal anterior cingulate.

the data from the choice task. First, we identified a seed ROI involved in value processing by conducting a whole-brain analysis capturing the effect of the size of the overall monetary reward available on a given trial, as reflected in the value of the delayed outcome (\$40, \$30, \$20, or \$10), on blood-oxygen-level-dependent (BOLD) signal ($p < .001$, $k > 10$ voxels). This analysis yielded a value-related ROI in

the caudate (as well as incidental activations in bilateral occipital cortex and the right motor cortex). The first eigenvariate of the time series of voxels in this seed ROI was then deconvolved from the hemodynamic response function in order to generate an estimated neuronal time series (Gitelman, Penny, Ashburner, & Friston, 2003). This time series was then multiplied by a vector indicating the onsets

of each framing condition (independent, sequence) and reconvolved with the hemodynamic response function. The resulting predictor was entered into a new GLM, along with a vector indicating the onsets of each task condition (independent framing, sequence framing), the original eigenvariate time series for the seed region, and covariates of no interest (same covariates as in the preceding analyses). Parameter estimates for the PPI interaction term were tested for condition-dependent connectivity.

Results

Behavioral data. On average, participants chose the patient option 59.3% of the time and the impatient option 40.7% of the time; this corresponded to a mean preference of 2.66 on the 4-point scale. Participants earned an average bonus of \$26 after an average delay of 16.1 days (see Table S2 in the Supplemental Material for additional details). Response time (RT) did not differ between patient and impatient choices overall ($p > .39$), within the independent-framing condition (mean difference = 137 ms, $p > .35$) or within the sequence-framing condition (mean difference = 98 ms, $p > .5$). Moreover, condition and choice type did not have a significant interaction effect on RT ($p > .7$; see Table S2). We did, however, observe a significant main effect of framing condition on RT, $F(1, 27) = 34.5, p < .001$; participants responded more quickly in the independent-framing condition ($M = 2,871$ ms) than in the sequence-framing condition ($M = 3,269$ ms). We accounted for this difference in our fMRI analysis by modeling the temporal derivative of the hemodynamic response in each condition (see Imaging Analysis). Participants' choices did not indicate a significant overall difference in patience between the sequence- and independent-framing conditions ($p > .84$), probably owing to the 4-point scale's inability to capture fine-grained differences in preferences. A comparison of the brain regions associated with more patient choices across the framing conditions therefore provides a relatively conservative test of the possibility that sequence framing affects the cognitive processes associated with patience.

Neural evidence that sequence framing affects the relative contributions of imagination and willpower to patience. First, we examined the extent to which framing choice options as sequences, rather than independent events, increased the relative contributions to patient behavior of brain regions associated with imagination versus willpower. To do this, we compared patience-related activation in the ROIs associated with imagination (mPFC, PC, and right hippocampus) with patience-related activation in the ROIs associated with willpower (right dlPFC, left dlPFC, and dACC; Fig. 2a). Although the simple effect of framing condition on activation in the imagination ROIs did not

reach significance, we observed a significant Network (imagination, willpower) \times Framing Condition (sequence, independent) interaction effect on patience-related activation, $F(1, 27) = 7.61, p = .01, d = 0.52$ (Figs. 2b and 2c). Specifically, patience in the independent-framing condition was more associated with activation in the willpower ROIs than was patience in the sequence-framing condition, whereas patience in the sequence-framing condition was more associated with activation in the imagination ROIs than was patience in the independent-framing condition. These results were confirmed using an alternative set of willpower ROIs, defined by an automated meta-analysis on neurosynth.org, in place of our functionally defined willpower regions.

To supplement these ROI analyses, we conducted whole-brain analyses (exploratory threshold of $p < .005$ and 5 contiguous voxels; Lieberman & Cunningham, 2009). The mPFC emerged as more associated with patience in the sequence-framing condition than in the independent-framing condition (sequence $>$ independent contrast). In contrast, activation in the right and left dlPFC was more associated with patience in the independent-framing condition than in the sequence-framing condition (independent $>$ sequence contrast; see Fig. S2 in the Supplemental Material).

Neural evidence that sequence framing increases the role of imagination in valuation. To the extent that imagination affects patience in the sequence framing-condition by changing how people value the different choice options, there should be greater functional connectivity between imagination ROIs and regions associated with value processing in the sequence-framing condition relative to the independent-framing condition. Moreover, to the extent that this relationship operates independently of willpower, there should not be preferential connectivity between willpower ROIs and regions associated with value processing in the sequence-framing condition. To test these predictions, we conducted a PPI analysis of the functional connectivity between our seed value-processing ROI in the caudate and our a priori ROIs associated with imagination and willpower, respectively.

Although activation in both the imagination and the willpower ROIs was significantly correlated with activation in the caudate overall (both $r_s > .5$, both $p_s < .01$; p for the difference $> .1$), this relationship was significantly modulated by framing (see Fig. 3). Specifically, the imagination ROIs were more functionally connected with the caudate in the sequence-framing condition than in the independent-framing condition, $t(27) = 3.36, p < .003, d = 0.63$. In contrast, the willpower ROIs were no more functionally connected with the caudate in one condition than the other ($p > .8$). A comparison of the PPI parameter estimates for the imagination and willpower ROIs showed

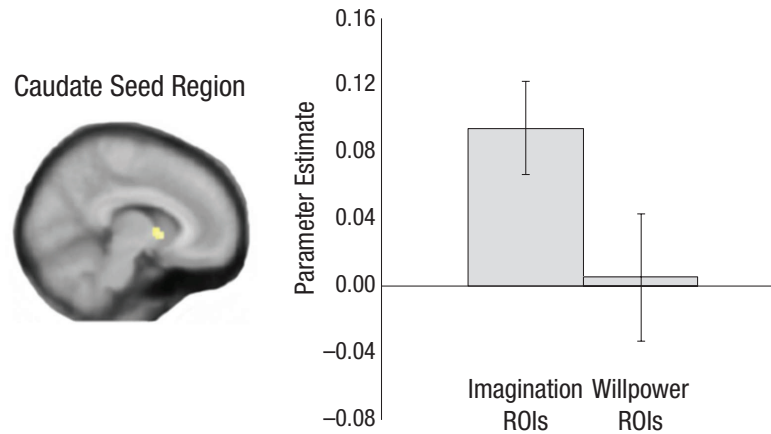


Fig. 3. Results of the analysis of functional connectivity to the value-processing seed region in the caudate. The graph shows the parameter estimates from the psychophysiological interaction (PPI) analysis, separately for the imagination regions of interest (ROIs) and the willpower ROIs. Positive numbers indicate greater connectivity in the sequence-framing condition than in the independent-framing condition. The location of the seed region is shown in the brain image. Error bars represent ± 1 SEM.

that they were significantly different, $t(27) = 2.51, p = .018, d = 0.47$. These results demonstrate that sequence framing increases the functional connectivity of regions associated with imagination to a region associated with value processing. Moreover, they demonstrate that imagination ROIs are functionally dissociable from willpower ROIs in their relationship to value processing. To the extent that imagination increases patience under sequence framing by changing the reward values associated with the options, it appears to do so in a way that does not rely on an increased contribution from regions associated with willpower.

Discussion

Research in psychology and economics has identified a variety of framing effects on patience, but there has been little unity in the cognitive explanations for those effects (Lempert & Phelps, 2016). In recent years, researchers have increasingly speculated that imagining future outcomes can promote patience (Benoit et al., 2011; Bulley et al., 2016; Ersner-Hershfield, Garton, Ballard, Samanez-Larkin, & Knutson, 2009; Ersner-Hershfield, Wimmer, & Knutson, 2009; Mitchell et al., 2011; Peters & Büchel, 2010; Sasse et al., 2015)—a possibility supported by the observation that imagining future outcomes reduces temporal discounting (Kim, Schnall, & White, 2013). However, it has often been difficult to capture the relationship between imagination and patience empirically (O’Connell, Christakou, & Chakrabarti, 2015), and the role of imagination in framing effects has been unknown.

The present results suggest that imagination has a role in time-framing effects. Reframing outcomes as sequences

promoted self-reported and independently coded imagination. This reframing also increased the degree to which patience was associated with activation in imagination ROIs, relative to willpower ROIs. Finally, reframing increased the functional connectivity between imagination ROIs, but not willpower ROIs, and regions associated with valuation.

By integrating methods from studies of episodic future simulation and decision neuroscience, we investigated the roles of imagination and willpower in time-framing effects while addressing two main research challenges concerning the relationship between imagination and behavior. One of these challenges is to increase confidence that imagination-related processes are among those being manipulated and measured. Brain regions associated with imagination, especially the mPFC, have been associated with a variety of other activities, including memory, social cognition, affective experience, and valuation. To increase the likelihood that the observed results pertain to imagination, we used explicit and implicit measures of imagination in Experiment 1b and a priori ROIs associated with imagination in Experiment 2. Although this approach does not completely rule out the possibility that processes other than imagination contributed to the results, it does provide converging behavioral and fMRI evidence consistent with the possibility that sequence framing affected imagination-related processes.

The other challenge is to establish a role for imagination in choice behavior. Previous studies have often examined the extent to which more patient people also have greater activation in imagination-related brain regions (Ersner-Hershfield, Wimmer, & Knutson, 2009; Mitchell et al., 2011), but this approach limits inferences regarding

imagination's role in choice behavior itself. Following studies measuring imagination-related activation and patience within the context of a single paradigm (Benoit et al., 2011; Peters & Büchel, 2010), we measured imagination as participants made patient and impatient decisions. By capturing imagination's role in time-framing effects both between participants (Experiment 1) and within participants (Experiment 2), our study provides stronger support for this role than could be offered by either approach alone. At the same time, a potential downside of capturing behavior within the scanner environment was that it limited the degree to which participants could express fine-grained differences in preference between choice options, possibly reducing sensitivity. Accordingly, the current study was a fairly conservative test of the role of imaginative processes in decisions under sequence framing. This may explain why sequence framing did not significantly increase the relationship between patience and imagination overall in Experiment 2, even though it did alter the degree to which patience was associated with imagination relative to willpower.

Although an abundance of research has established a role for willpower and related cognitive-control constructs in patience, little is understood about the relationship between these and other possible routes to patient behavior. In the current experiments, sequence framing appeared to promote the role of imagination, but not willpower, in valuation and behavior. Thus, our findings provide evidence that the effects of imagination on patience do not reduce to effects of willpower. Accordingly, sequence framing may be an especially promising means to sustain patience when the ability to exert willpower is compromised, such as under conditions of high cognitive load.

Action Editor

Eddie Harmon-Jones served as action editor for this article.

Author Contributions

A. C. Jenkins and M. Hsu designed the experiments. A. C. Jenkins collected the data. A. C. Jenkins analyzed the data and drafted the manuscript, with input from M. Hsu. Both authors approved the final version of the manuscript for submission.

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Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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Supplemental Material

Additional supporting information can be found at <http://journals.sagepub.com/doi/suppl/10.1177/0956797617698133>

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