Supplementary Methods

Subjects: Fourteen Princeton undergraduate and graduate students were recruited to participate in the study, including 9 females and 5 males. The mean age was 21.4 years, with standard deviation 1.8; all subjects were right-handed. Informed consent was obtained using a consent form approved by the Institutional Review Panel at Princeton University.

Subjects were instructed that they were participating in a study to determine how people discount value for time. They were instructed that there were no correct answers, but that they should state their preference in a series of choice tasks. For each task they would choose between two options. Subjects were instructed that at the end of the experiment they would receive one of their choices (randomly selected from the set of all of their choices), which would be paid to them in the form of an Amazon.com gift certificate. Given this, subjects were explicitly told that because of this payment scheme they should make each choice as though it were the one they were actually going to receive.

Behavioral task: Subjects viewed a rear-projected computer image by which the task was presented. Choices were made using an MRI-compatible button box. For each choice, subjects were allowed as much time as they desired to make their selection. The two choices were presented on either side of the screen, with the smaller, earlier reward always presented on the left (Figure S1). Two yellow triangles underneath the two money/time pairs indicated that a choice could be made. Participants were allowed as much time to respond as desired. Responses were made by pressing one of two buttons

corresponding to the location of the options on the screen (response time mean was 3.78s with standard deviation 2.34). Once the subjects indicated their preference, the associated yellow triangle turned red for 2s to signal that the selection was successfully recorded. Following this, the screen remained black for a 12s period until the next choice was presented. The task was paused every 7 minutes to allow subjects to rest. The task took approximately 20 minutes to complete.

The first two questions in the task were fixed to allow subjects to get acclimated to task performance. The first question required subjects to choose between the same dollar amount available at two different delays (e.g. $27.10 in 2 weeks vs. $27.10 in 1 month and 2 weeks); all subjects chose the reward at the earlier time (i.e., 2 weeks). The second question asked subjects to select between two dollar amounts in which the early value was less than 1% of the delayed value (e.g. $0.16 today vs. $34.04 in 1 month and 2 weeks). All subjects selected the later, larger dollar amount for this question.

The remaining choices were randomly ordered and determined for each subject according to the following scheme. Subjects faced *all* choice pairs generated by combining the following parameters. The delay to the early reward (i.e., d), was selected from the set {today, 2 weeks, 1 month}. The delay between the late reward and the early reward (i.e., d'-d) was selected from the set {2 weeks, 1 month}. The percent difference in dollar amounts between the two rewards (i.e., (R'-R)/R) was selected from the set {1%, 3%, 5%, 10%, 15%, 25%, 35%, 50%}. We eliminate the cases in which the late reward would be received more than six weeks from the date of the experiment (i.e., the case d

equals one month and *d'-d* equals one month). For each trial, the early dollar amount ($*R*) was randomly drawn from a Gaussian distribution with mean $20 and standard deviation $10, clipped to give a minimum of $5 and a maximum of $40. The larger dollar amount ($*R'*) was set so that ($*R'*-$*R*)/$*R* was the desired percent difference.

At the end of the experiment, all options chosen by the subject were randomly arranged and participants blindly selected one, which was then implemented. The specified dollar amount was paid to the participant at the corresponding time in the form of an Amazon.com gift certificate delivered by email. This method of delivery ensured that transaction costs were equalized across all delay options. Participants were also paid $15 in cash for performing the task; they were not told they would receive this money until the experiment was complete.

FMRI acquisition: Imaging was performed on a 3 Tesla Siemens Allegra scanner at Princeton University. A high-resolution (0.5mm x 0.5mm x 1.0mm) T1-weighted anatomical image was first acquired to enable localization of functional images. Whole-brain functional images were acquired in 26 axial slices (64 x 64 voxels; in plane resolution 3mm x 3mm; 3mm slices with 1mm slice gap) approximately 30^{o} off of the AC-PC line at a repetition time of 2s. This imaging method reduces signal loss from the orbitofrontal cortex due to susceptibility artifacts (Jim Rilling, personal communication). Prior to analysis, the images were realigned, coregistered to the subject's T1 image, corrected for slice time artifacts, normalized to Montreal Neurological Institute coordinates (resampled at 4mm x 4mm x 4mm), and smoothed with an 8mm full-width at

half maximum Gaussian kernel using SPM2 (*S1*). At the start of each functional scanning run, the screen remained black for 8s to allow time for magnetization to reach steady state. These associated first four images were discarded from the analysis. Because subjects were allowed arbitrary time to render their preferences, the duration of the experiment was somewhat variable. However, the majority of subjects completed the task within three 7 minute scanning runs.

FMRI Analysis: Data were modeled and analyzed using an event-related design. The general linear model (GLM) and random effects analyses presented in Figures 1 and 2 were performed using SPM2. Two regressors were included in a single GLM equation to identify β and candidate δ regions at the voxel level. Each regressor modeled effects predicted for the time series of fMRI data in the corresponding type of area. For the purpose of constructing the regressors, each time series was divided into decision epochs (corresponding to the time between presentation of the choice and the subject's recorded response) and baseline (or rest) periods. As described further below, the time series fMRI data to be predicted were generated at two second intervals, extending from 4s prior to the decision epoch to 14s following it.

The β regressor was generated by convolving a canonical hemodynamic response function with a dummy variable that equaled 1 during decision epochs for trials in which the early reward option was available immediately (i.e., $d=0$), equaled –0.5 during decision epochs in which the early reward was available only with a delay (i.e., $d>0$), and equaled zero during baseline periods. The δ regressor was generated by convolving a

canonical hemodynamic response function with a dummy variable that equaled one during all decision epochs and zero during baseline periods. β and δ areas were identified by performing t-tests on the coefficients estimated for the respective regressors.

To rule out effects of two potential confounding variables, response time and discounted value of the choices, two separate manipulations were performed. First, we generated additional regressors scaled by these confounding variables, to include in the basic GLM model described above. This allowed us to identify β and δ regressors in the presence of the confounds. For RT, the regressor modeled subject-specific trial-to-trial variations in RT convolved with decision epoch. For discounted value, the regressor modeled the estimated value of the options in the choice set, as described in footnote 29 of the report. Additionally, we performed hierarchical regressions in which the effects of the confounding variables were fit to the data in a first-stage GLM. Then the β / δ analysis described above was performed on the residual data after subtracting out the effect of the confounds.

Results are reported for brain areas that are composed of 5 or more contiguous voxels each significant at an uncorrected p value of < 0.001. This combination of p value and extent thresholding reduces the effective per voxels false positive rate to robust levels (*S2*). In addition, $p < 0.001$ is below the threshold required to ensure a false discovery rate (Type II error) of < 0.05 (*S3*; $t=4.15$ for β analysis and $t=3.83$ for δ analysis).

All other analyses were performed using self-written tools in Matlab 6.5 (The Mathworks, Natick, MA), with ANOVAs calculated with JMP IN 5.1 (SAS Institute, Inc., Cary, NC). Mean time series were calculated for each identified brain region by first converting each voxel's BOLD signal to percent signal change and then averaging over all voxels in the relevant region. Since choices could be made at any point relative to the onset of scans, event-related signals were calculated by linear interpolation beginning 4s prior to the choice and continuing at 2s intervals for 14s.

To confirm robustness of the main results reported in the paper (Figures 1 and 2), we subjected the data acquired from the β- and δ-areas analyses to an ANOVA to test directly for the significance of differences in their modulation by delay (*d*). Mean time-series were calculated for each identified brain area and entered into a 3-way ANOVA (region, time relative to choice, and delay *d* until first available money option). This analysis revealed that δ areas were differently affected by reward delay compared with β areas (region x time x delay interaction, $p < 0.0001$). Similar results were also achieved by grouping brain areas by role (either β or δ; region x time x role interaction, $p < 0.0001$).

Analysis of activity combined across β and δ areas (figure 4): To allow for unbiased averaging over all β and δ brain regions, percent signal changes were first z-score corrected before analyses were performed. The peak signal was calculated for each event by averaging the BOLD signal at 4s and 6s following the choice. It was these peak values that were mean-corrected and normalized for standard deviation.

Supplementary References

S1. K.J. Friston, *et al.*, *Hum. Brain Mapp.* **2**, 189 (1995).

S2. S.D. Forman, *et al.*, *Magn. Reson. Med.* **33**, 636 (1995).

S3. C.R. Genovese, N.A. Lazar, T. Nichols, *NeuroImage* **15**, 870 (2002).

Supplementary Figure Legends

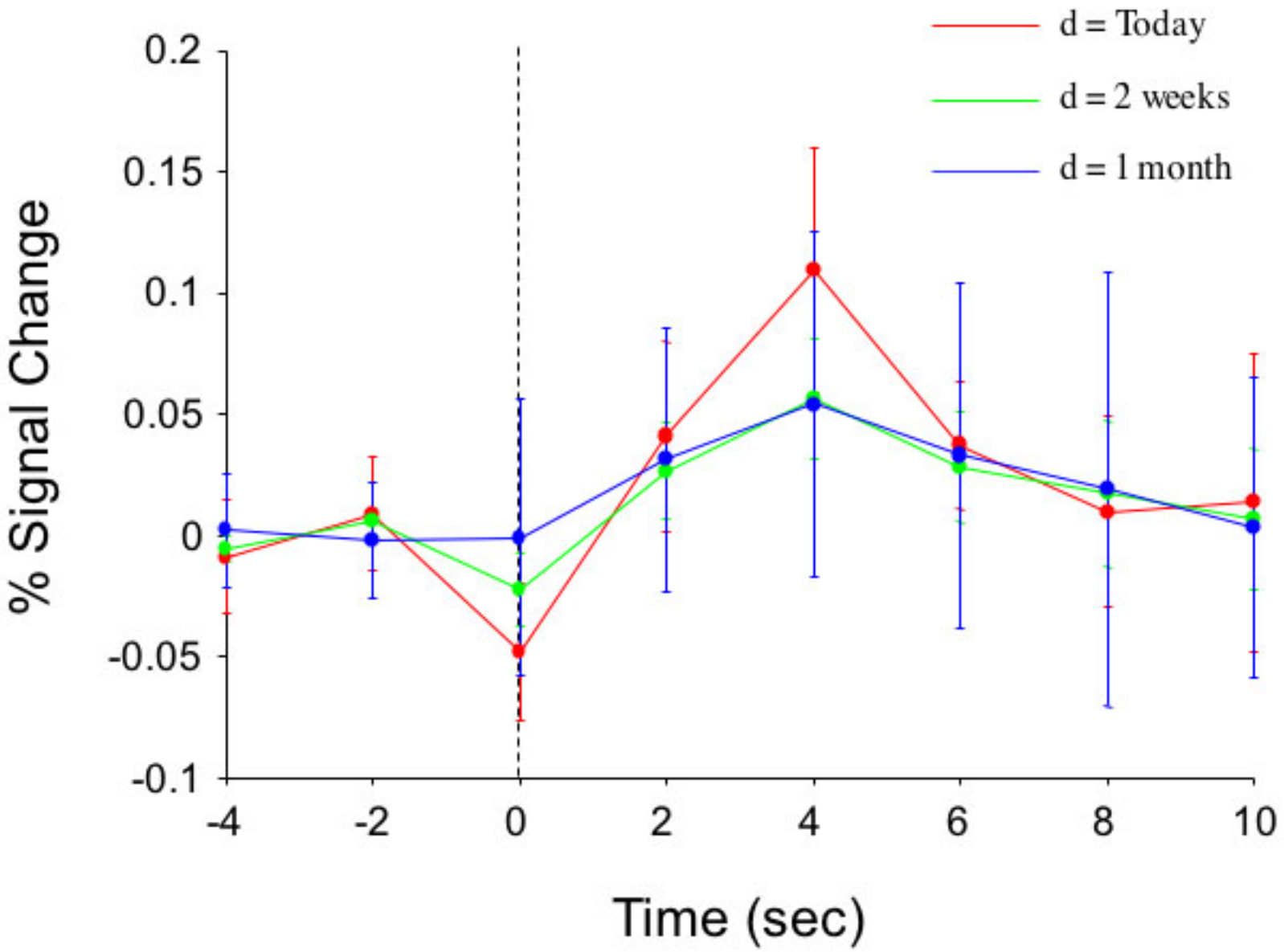
Figure S1. Experiment design. Subjects were presented with a series of decisions between two dollar amounts available at two different dates. The lesser, earlier dollar amount was always presented on the left side of the display. Yellow triangles beneath the options indicated that a response could be made. Subjects were instructed to take as much time to choose as desired. After the choice was made, the corresponding triangle was colored red and left visible for 2s before the screen was turned black. The blank screen persisted for 12s before the next question appeared.

Figure S2. Mean time series in the left hippocampus. BOLD signals were aligned to the time of subjects' choices (time=0s; dashed line), and averaged over choices and subsequently subjects. Shown is the mean time course from the voxels identified in the β analysis with standard error computed across subjects (n=14).

Table S1. Summary of significant voxels from β analysis. X, Y, and Z coordinates are reported relative to the MNI template (mm). *n* is the number of contiguous voxels all significant at $p < 0.001$.

Table S2. Summary of significant voxels from δ analysis. X, Y, and Z coordinates are reported relative to the MNI template (mm). *n* is the number of contiguous voxels all significant at $p < 0.001$.


$20.28
Today
$23.32
1 month
$20.28
Today
$23.32
1 month
Free Response
2 s
12 s


d = Today
d = 2 weeks
d = 1 month
% Signal Change
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-4
-2
0
2
4
6
8
10
Time (sec)

β analysis: Summary of significant voxels

	X	Y	Z	Max T	n
Medial OFC	-8	48	-4	5.034	16
Ventral striatum	6	8	-4	4.369	5
L Posterior hippocampus	-26	-38	-8	4.582	7
Medial PFC	0	44	12	6.793	74
Posterior cingulate cortex	-8	-28	32	5.354	21

All voxels significant at $p < 0.001$

δ analysis: Summary of significant voxels

	X	Y	Z	Max T	n
Visual cortex	-4	-80	0	15.256	1125
PMA	0	12	56	5.684	17
SMA	4	30	40	5.265	10
R Posterior parietal cortex	40	-60	44	7.299	185
L Posterior parietal cortex	-32	-60	52	8.854	67
R DLPFC	44	44	16	7.718	58
R VLPFC	40	20	-8	8.196	39
R Lateral OFC	24	50	-12	4.846	5

All voxels significant at $p < 0.001$