Behavioral and neural correlates of increased self-control in the absence of increased willpower

Eran Magen[a,1,2], Bokyung Kim[b,1], Carol S. Dweck[b,2], James J. Gross[b], and Samuel M. McClure[b]

[a]Department of Counseling and Psychological Services, University of Pennsylvania, Philadelphia, PA 19104; and [b]Department of Psychology, Stanford University, Stanford, CA 94305

Contributed by Carol S. Dweck, May 21, 2014 (sent for review September 28, 2013)

People often exert willpower to choose a more valuable delayed reward over a less valuable immediate reward, but using willpower is taxing and frequently fails. In this research, we demonstrate the ability to enhance self-control (i.e., forgoing smaller immediate rewards in favor of larger delayed rewards) without exerting additional willpower. Using behavioral and neuroimaging data, we show that a reframing of rewards (*i*) reduced the subjective value of smaller immediate rewards relative to larger delayed rewards, (*ii*) increased the likelihood of choosing the larger delayed rewards when choosing between two real monetary rewards, (*iii*) reduced the brain reward responses to immediate rewards in the dorsal and ventral striatum, and (*iv*) reduced brain activity in the dorsolateral prefrontal cortex (a correlate of willpower) when participants chose the same larger later rewards across the two choice frames. We conclude that reframing can promote self-control while avoiding the need for additional willpower expenditure.

temporal discounting | judgment and decision-making | neuroeconomics | reward reframing

Self-control is highly desirable and correlates with beneficial outcomes such as financial stability (1, 2), academic achievement (3, 4), social success (5, 6), and healthy living (1, 7). Many cognitive and behavioral strategies may be used to achieve self-control (8). We contrast two broad self-control strategies that affect how people respond to an immediately available, tempting reward. First, people may attempt to directly modulate their behavior through effortful willpower exertion, to select delayed rewards despite the presence of distracters or temptations. Alternatively, the perception of temptations may be altered so as to promote self-control. Exerting willpower is taxing and hence often of limited efficacy (9). By contrast, changing how outcomes are perceived and valued has the benefit of more automatically shaping behavior and may prove a superior target for interventions and long-term behavioral change.

Recent findings support the plausibility of independently assessing changes in reward valuation and changes in willpower exertion because brain systems underlying reward valuation are distinct from those associated with willpower exertion (10, 11). More specifically, studies of intertemporal choice link valuation processes to the ventromedial prefrontal cortex and striatum (10, 12–14), whereas willpower exertion is associated with the dorsolateral prefrontal cortex (dlPFC) (10, 11, 15). However, no study has demonstrated that self-control can be engaged in a way that influences monetary choice behavior in an intertemporal choice context without the exertion of additional willpower.

Our goal was to demonstrate that the ability to make far-sighted choices may be enhanced without requiring the use of additional willpower, by altering how rewards are perceived and valued. We triangulated the process of altering reward perception and valuation by obtaining data through self-report (subjective reward valuation), behavioral measures (monetary choices), and neuroimaging (neural activity underlying reward valuation versus willpower exertion). In doing so, we capitalized on the hidden-zero effect, a subtle cognitive framing manipulation (16) that increases selection of larger delayed monetary rewards over smaller immediate monetary rewards.

In our paradigm, instead of presenting choices in a traditional hidden-zero format (e.g., "Would you prefer [A] $5 today OR [B] $10 in a month?"), choices are presented in an explicit-zero format, which references the nonreward consequences of each choice (e.g., "Would you prefer [A] $5 today and $0 in a month OR [B] $0 today and $10 in a month?"). Including future outcomes in all choice options has been argued to reduce the attentional bias toward immediate rewards that contributes to impulsive behavior (17).

Of course, this change in attention may influence reward evaluation (by making the delayed reward more valued relative to the immediate one), or it may prompt greater effortful exertion of willpower. In terms of the latter possibility, willpower has been argued to arise from conflict in the decision process (11), and increased attention to future rewards (or nonrewards) may enhance conflict with a desire for immediate gratification. In this case, an effortful process might be triggered. We tested these two alternatives for the basis of the hidden-zero effect. In study 1, we examined the effect of the explicit-zero framing on participants' subjective valuation of immediate and delayed rewards and linked this effect to monetary choice. In study 2, we used functional magnetic resonance imaging (fMRI) to identify the neural effects of reframing on reward valuation, monetary choice behavior, and willpower exertion.

Results

Study 1: Effect of Reframing on Subjective Reward Value. The hidden-zero manipulation may change choice behavior by influencing how

Significance

Self-control encompasses behaviors that enable us to forgo immediate temptations in favor of more beneficial delayed rewards. Self-control has been associated with superior academic, professional, and personal outcomes. Research primarily focuses on the ability to exert willpower to deliberately suppress immediate desires. However, willpower is taxing and susceptible to lapses and therefore makes a poor tool for long-term behavioral change. In this study we ask whether people can enhance their apparent self-control without increasing effortful exertion of willpower. We investigate a cognitive reframing manipulation that, behaviorally, increases self-control without an increase in estimated willpower. Functional brain imaging demonstrates that the reframing manipulation alters responses in brain reward areas and decreases activity in regions of lateral prefrontal cortex linked to willpower exertion.

Author contributions: E.M., B.K., C.S.D., J.J.G., and S.M.M. designed research; E.M. and B.K. performed research; E.M., B.K., and S.M.M. analyzed data; and E.M., B.K., C.S.D., J.J.G., and S.M.M. wrote the paper.

The authors declare no conflict of interest.

[1]E.M. and B.K. contributed equally to this work.

[2]To whom correspondence may be addressed. E-mail: dweck@stanford.edu or eranm@upenn.edu.

This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1408991111/-/DCSupplemental.

rewards are evaluated and/or by encouraging greater willpower exertion. We evaluated these possible mechanisms using two tasks: a monetary choice task and subjective valuation task (*SI Note A*). In the monetary choice task, participants chose between smaller immediate and larger delayed reward pairs. Reward pairs were presented in both the hidden-zero and explicit-zero formats. In the subjective valuation task, the reward outcomes from the choice task were presented individually in hidden-zero or explicit-zero format, and participants rated their expected satisfaction for each outcome. Control participants repeated the tasks twice with rewards presented only in the hidden-zero format to examine possible effects of time on task (Table S1).

In both tasks, participants evaluated monetary rewards that varied in magnitude and in delay until receipt. People discount rewards on the basis of delay, a process known as delay discounting (9). We analyzed discount rates, the rates at which reward values are reduced as delay increases, by fitting a hyperbolic function to data from the valuation and choice tasks. For the valuation task, we fitted hyperbolic functions to best predict the ratings for standalone rewards. For the choice task, we obtained best fitting hyperbolic functions by assuming that participants tended to select the option with greater discounted value (*SI Note A, Method*). This assumption allowed us to estimate discount rates (k; Eq. **S1**) for participants in each task and framing condition. Discount rates are plotted for each participant in the hidden-zero (Fig. 1*A*, *Left*) and explicit-zero conditions (Fig. 1*A*, *Right*). Lower discount rates are associated with (*i*) decreased subjective value for immediate rewards relative to delayed rewards in the valuation task and (*ii*) more choices for delayed rewards in the choice task.

We had four hypotheses about how discount rates would change with framing conditions.

1a. Participants will exhibit lower rates of temporal discounting when choices are framed in the explicit-zero format compared with the hidden-zero format.

This prediction follows from our previous work showing that people chose delayed rewards more often when choices were framed in the explicit-zero format than the hidden-zero format (16).

1b. Participants will exhibit lower rates of temporal discounting in the choice task compared with the valuation task.

We reasoned that willpower recruitment occurs when participants choose between reward pairs but not when participants state the subjective value of standalone rewards that do not require a choice and do not present an impulse to override (11). Recruitment of willpower in the choice task should be evident in increased selection of delayed rewards and, consequently, smaller estimated discount rates relative to the valuation task. Differences in discount rates estimated in the choice and valuation tasks can thereby serve as an index of willpower.

1c. For the explicit-zero framing, participants will exhibit lower discount rates in both tasks, and the extent of reduction in discount rates will be similar across tasks.

We reasoned that if explicit-zero framing influenced behavior by changing subjective valuation alone, then (*i*) the framing effect should be evident in both tasks (because both involve judgments of reward value) and (*ii*) the size of the framing effect should be similar in both tasks (because valuation is posited to influence discount rates equally in both tasks). By contrast, if explicit-zero framing influenced behavior by willpower exertion, then (*i*) the framing effect should be evident in the choice but not valuation task (because willpower is assumed to influence discount rates selectively in the choice task) and (*ii*) the size of the framing effect should be larger in the choice task.

1d. Framing-dependent changes in reward valuation and choice behavior will be positively correlated.

The same logic underlying hypothesis 1c implies that the degree to which reframing changes discount rates in individual participants should be the same in both the valuation and choice tasks. We can further test for an equivalence by correlating framing-dependent differences in discount rates across both tasks.

In support of hypothesis 1a, discount rates were lower in the explicit-zero condition compared with the hidden-zero condition in both tasks (Wilcoxon signed rank test; $P < 0.01$ and $P < 0.005$, respectively; Fig. 1*B*). To illustrate the magnitude of the effect, consider a participant facing a choice between $100 in 6 mo and a smaller amount immediately. In the hidden-zero frame, a participant with the median discount rate would choose the smaller immediate reward if it were greater than $34.15. In contrast, in the explicit-zero frame, the immediate reward would need to be greater than $42.70 in order for same participant to select it, a 25% increase in the size of the smaller immediate reward necessary to forgo the larger delayed reward.

The valuation task allowed us to test whether the effect of choice framing on discount rates resulted from changes in the valuation of immediate rewards, delayed rewards, or both because participants evaluated standalone rewards. Participants

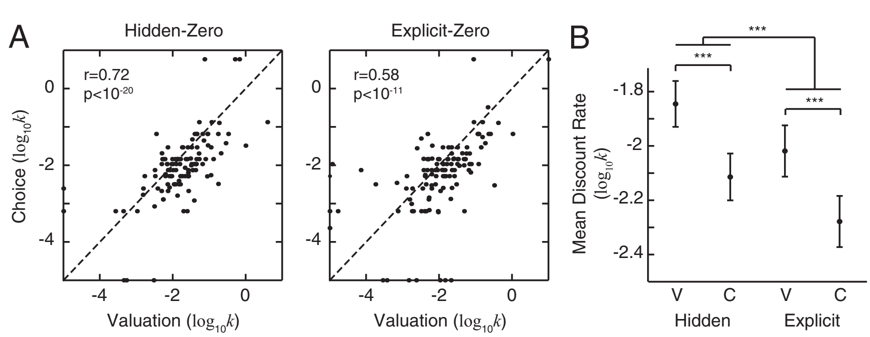

Fig. 1. Delay discounting was influence both by reward framing (hidden- or explicit-zero) and task. (*A*) Discount rates were estimated for each participant in a valuation task of standalone rewards (*x* axes) and in a choice task of preferences among pairs of rewards (*y* axes). For both tasks, rewards were presented sequentially in a hidden-zero (e.g., $5.00 in 2 wk) and an explicit-zero (e.g., $0.00 today and $5.00 in 2 wk) frame. Points in each plot are separate subjects. Dashed lines indicate equivalent discount rates in the valuation and choice tasks. Discount rates were significantly lower in the choice tasks than in the valuation tasks (hidden-zero: $P < 10^{-4}$; explicit-zero: $P < 0.005$), consistent with the elicitation of willpower during choice. (*B*) Additionally, discount rates were significantly lower when outcomes were presented in the explicit-zero than in the hidden-zero frame ($P < 0.001$ for discount rates averaged over the valuation and choice tasks). ***$P < 0.001$.

reported lower subjective values for immediate rewards presented in explicit-zero ($M = 60.59$, $SD = 21.46$) compared with hidden-zero format [$M = 65.87$, $SD = 22.12$; $t(121) = 3.89$, $P < 0.001$, $d = 0.24$]. Presentation format had no effect on the subjective value of delayed rewards [explicit-zero: $M = 57.57$, $SD = 22.07$; hidden-zero: $M = 57.23$, $SD = 22.23$; $t(121) = 0.28$, $P = 0.78$]. Control participants did not exhibit a change in subjective value for immediate rewards [$\Delta M = 0.31$, $SD = 10.01$, $t(59) = 0.24$, $P = 0.81$] or for delayed rewards [$\Delta M = 0.67$, $SD = 11.05$; $t(59) = 0.47$, $P = 0.64$]. Thus, the explicit-zero format lowered the subjective value of immediate rewards without changing the subjective value of delayed rewards, thereby increasing the relative subjective value of delayed rewards.

As predicted in hypothesis 1b, discount rates were lower when estimated from choice data than from valuation data in both the hidden-zero (Wilcoxon signed rank test, $P < 0.001$) and explicit-zero formats ($P < 0.001$; Fig. 1*B*). This difference suggests that willpower is preferentially engaged by the choice task. Control participants (data not shown) did not exhibit a change in discount rate across repetitions of the hidden-zero tasks, ruling out time on task as a confounding factor (choice task: Wilcoxon signed rank test, $P = 0.48$; valuation task: $P = 0.09$).

We tested hypothesis 1c by comparing how discount rates changed across presentation formats for the choice and valuation tasks [i.e., $\log(k_{hidden}) - \log(k_{explicit})$ for each task and subject]. We found no difference in framing effect size across tasks (Wilcoxon signed rank test, $P = 0.90$), supporting the idea that reframing primarily influenced reward valuation.

We tested hypothesis 1d with a robust regression to accommodate outlying discount rates arising from the small percentage of participants who chose all smaller-sooner or all larger-later rewards. As predicted, we found a significant relationship between the framing effect in the valuation and choice tasks [$t(120) = 2.53$, $P = 0.013$]. The robust regression identified nine outlier values; the correlation coefficient for the remaining data were $r(111) = 0.21$ ($P = 0.026$).

Taken together, these results suggest that reframing primarily affected subjective evaluation of rewards. Although the differences in delay discounting between the valuation and choice tasks indicated that willpower was an important component of decision-making, our findings suggest that explicit-zero framing influences behavior principally by changing valuation processes.

Study 2: Effect of Reframing on Neural Reward Representations. Study 1 suggests that the explicit-zero framing led participants to make more far-sighted choices without influencing willpower exertion. Based on findings that willpower exertion relies on increased dlPFC activity and down-regulation of valuation and emotional systems (10, 18, 19), we used fMRI to test whether reframing effects on choice behavior were linked to changes in the neural processes underlying valuation, willpower exertion, or both. Neural activity was measured with fMRI while subjects made choices between smaller immediate rewards and larger delayed rewards presented in hidden-zero and explicit-zero formats (*SI Note B*).

For the second study, we had five hypotheses:

2a. As in study 1, participants will exhibit lower rates of temporal discounting when choices are framed in the explicit-zero format compared with the hidden-zero format.

2b. Choices presented in the explicit-zero format will activate reward-related brain areas less than in the hidden-zero format.

Study 1 showed that reframing specifically influenced the subjective value of immediate rewards. Responses in brain reward areas scale with the value of immediate and delayed rewards, with preferential responses to immediate outcomes (12, 13). A selective impact on the valuation of immediate rewards therefore predicts reduced overall reward-related brain activity in the explicit-zero frame relative to the hidden-zero choice frame.

2c. Framing-dependent changes in reward-related brain activations and choice behavior will be correlated.

The argument in hypothesis 2b further suggests that the extent to which framing alters reward valuation across individuals should be evident in correlated differences in discount rates and reward-related brain activity.

2d. The average activation in brain areas related to willpower will not differ between the explicit-zero and hidden-zero formats (although the percentage of choices for delayed rewards will differ).

Following directly from study 1, we expected willpower would be equally engaged on average in both cognitive frames.

2e. Choosing the larger-later reward will require less willpower exertion and will exhibit less brain activation in areas associated with willpower exertion when rewards are presented in the explicit-zero format compared with the hidden-zero format.

How reframing altered subjective valuation should be evident as reduced willpower required for the same far-sighted choice in the explicit-zero format relative to the hidden-zero format. Namely, if willpower was used when making the choice in the hidden-zero frame, then a framing effect on subjective value should make the delayed reward relatively more attractive and reduce the willpower required when making the same choice in the explicit-zero frame.

In agreement with both study 1 and hypothesis 2a, discount rates were lower when rewards were presented in the explicit-zero format than the hidden-zero format (Wilcoxon signed rank test, $P < 0.05$). If we again consider a participant facing a choice between \$100 in 6 mo and a smaller amount immediately, a 15% increase in the size of the smaller immediate reward necessary would be necessary to forgo the larger delayed reward in the explicit-zero (\$60.02) relative to the hidden-zero (\$52.14) frame.

To test hypothesis 2b, we measured differences in brain activity associated with reward valuation in each presentation format. Because monetary reward magnitudes and delays were equal across the two formats, we compared mean brain response as participants made decisions in the different cognitive frames. We refer to regression coefficients derived from the general linear model for the explicit-zero and hidden-zero format as β_{explicit} and β_{hidden}, respectively.

When comparing mean differences in β_{explicit} and β_{hidden} across participants, we found that regions in the dorsal and ventral striatum showed greater activity during choices made in a hidden-zero format compared with in explicit-zero format (Fig. 2*A*; paired *t* test between β_{explicit} and β_{hidden}; Table S2). This pattern of brain activity is consistent with the finding in study 1 showing higher subjective values for immediate rewards presented in the hidden-zero format compared with the explicit-zero format and supports hypothesis 2b.

We tested hypothesis 2c by determining how framing-dependent changes in striatal activity related to framing-dependent changes in choice behavior across participants. We calculated mean differences in activation ($\beta_{\text{hidden}} - \beta_{\text{explicit}}$) across striatal voxels for each subject and presentation format. Between participants, the size of the behavioral effect correlated with changes in striatal activity [$r(21) = 0.53$, $P < 0.01$; Fig. 2*B* and *SI Note B*]. This finding suggests that differences in reward valuation would be sufficient to account for the behavioral effect produced by explicit-zero reframing, in agreement with study 1 and supporting hypothesis 2c.

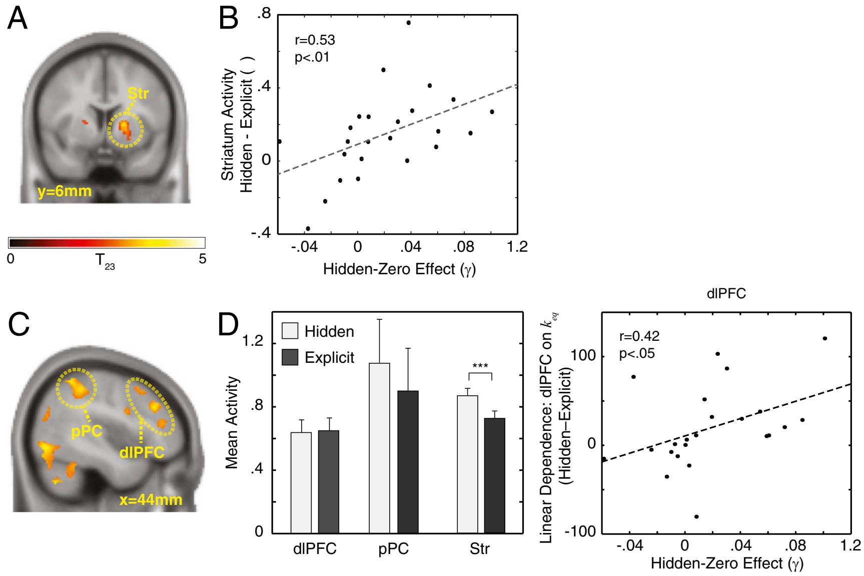

Fig. 2. Brain activity related to valuation and exertion of willpower were both influenced by choice framing. (*A*) Activity in reward-related dorsal and ventral striatum was greater for choices made in the hidden-zero than the explicit-zero frame. (*B*) Differences in striatal activity across framing formats correlated with individual differences in the size of the behavioral framing effect (γ; *SI Note B*). (*C*) The dlPFC and pPC have been implicated in the exertion of willpower and were active during decision-making. (*D*) Choice framing resulted in differences in mean neural activity in the striatum but not in the pPC or dlPFC regions. However, choice framing reduced dlPFC activity when participants selected larger later rewards, depending on the size of the framing effect (γ). ***$P < 0.001$.

Having established that reframing influenced brain valuation processes and choice behavior, our next set of analyses sought to determine how the reframing manipulation influenced willpower exertion. Hypothesis 2d posits that brain areas associated with willpower exertion would not exhibit framing-dependent differences in average activation, thereby supporting the premise that the cognitive framing manipulation does not influence willpower exertion. We tested for differences in mean dlPFC activity across the choice task in three separate analyses. First, we examined whole-brain activity to identify regions with mean differences in response during the choice period across cognitive frames. We found no differences in lateral PFC in this contrast, even at liberal statistical thresholds (no regions at $P < 0.3$, uncorrected). Second, to obtain greater statistical power, we examined responses in regions of interest surrounding lateral PFC foci identified in previous studies of intertemporal choice (10, 12). Brain activity did not differ across cognitive frames at these foci ($P > 0.5$ for left and right lateral PFC). Third, we replicated previous findings that dlPFC regions involved in decision-making can be identified by contrasting neural activity during choice periods with activity measured at rest (12). To confirm that dlPFC was involved in decision-making but was not differentially activated by the choice frames, we identified brain areas active during the choice period across the experiment. Significant responses were identified in the dlPFC [superior frontal gyrus (SFG)] and posterior parietal cortex (pPC in the intraparietal sulcus; Fig. 2*C*)—brain areas implicated in cognitive control processes. We calculated the average activity across the three significant clusters in the dlPFC/SFG (Montreal Neurological Institute coordinates: [38 16 48], [38 42 14]; [44 32 34]) for further analysis. We extracted mean estimates of neural activity separately for each presentation format (β_{hidden} and β_{explicit}) and conducted paired *t* tests to identify potential differences across choice frames. Choice frame did not affect activity in the dlPFC or pPC ($P > 0.3$). This null result may not be surprising given that dlPFC/pPC regions were selected based on minimal variance across trials in the experiment. The analysis was therefore biased against observing a difference in responses across framing conditions. Nonetheless, the regions of dlPFC and pPC identified were regions active during the decision-making process in our subjects.

We continued to focus on the dlPFC and pPC regions to test our last hypothesis (hypothesis 2e) that areas involved in willpower exertion will be less active for selection of larger-later rewards in the explicit-zero frame compared with the hidden-zero frame. To test this hypothesis, we looked for differences in activity when subjects chose delayed rewards, indicative of the use of willpower, and as a function of the equivalence discount rate, k_{eq}, which characterizes individual decisions (Eqs. **S5** and **S6**). Briefly, k_{eq} is the discount rate at which a participant would be indifferent about a decision and characterizes a choice in the sense that participants should have equal preferences for the smaller-immediate or larger-later outcomes for trials with the same k_{eq} (*SI Note C*).

Our prediction about the reduced need for willpower based on changes in subjective valuation can be specified in terms of k_{eq}. For any value of k_{eq}, we predicted that (*i*) willpower exertion required to select the larger-later outcome should be less in the explicit-zero than the hidden-zero frame, (*ii*) reduction in willpower exertion depends on the degree to which the framing manipulation influenced subjective value in each subject, and (*iii*) the benefit of the framing manipulation on willpower exertion should decrease as k_{eq} increases. The third prediction follows from the fact that the relative subjective values of delayed rewards increase with k_{eq} so that choices for larger-later outcomes become easier and require less willpower as k_{eq} increases.

We regressed k_{eq} against average responses from regions of the dlPFC and pPC identified above. We then contrasted the regression coefficients for k_{eq} against activity during hidden-zero trials (i.e., presumed greater dependence on willpower) against activity during explicit-zero trials (i.e., lesser dependence on willpower). Finally, we correlated differences in regression coefficients with a measure of the size of the framing effect, γ, across participants (*SI Note B*). This correlation analysis revealed a significant effect for the dlPFC [$r(21) = 0.45$, $P < 0.05$; Fig. 2*D*]. No significant effect was found in the pPC cluster identified [$r(21) = -0.24$, $P = 0.27$], suggesting that the pPC may not have been as directly involved in willpower exertion as the dlPFC. Nonetheless, these results show that for any given decision, choosing the larger-later reward required less dlPFC activity when the decision was framed in the explicit-zero format relative to the hidden-zero format, supporting hypothesis 2e.

Taken together, the fMRI results reinforce conclusions from study 1 that reframing (*i*) influenced valuation processes to a sufficient degree to account for the impact of framing on choice, so that (*ii*) choices for delayed rewards are increased without an overall increase in willpower, and (*iii*) requirements for willpower are lessened for any given far-sighted choice in the explicit-zero relative to the hidden-zero frame.

Discussion

Efforts to promote self-control can take one of two broad forms. The first promotes the use of willpower to overcome temptations (e.g., "Just say no!"). There are promising programs of research aiming to improve willpower efficacy (20, 21), but exerting willpower is difficult and may often need a helping hand. The second approach improves self-control by enhancing the appeal of far-sighted choices, so that avoiding temptations occurs more naturally and without additional cognitive effort (22–24).

We investigated a reframing manipulation that facilitated far-sighted monetary choices in a manner consistent with this latter approach, i.e., by changing the way rewards are perceived. We reported two complementary studies demonstrating how a reframing manipulation changed the way rewards were valued, and consequently the choices that participants made, without requiring additional willpower exertion to facilitate improved self-control. In both studies, it thus appeared that changes in valuation processes alone (as opposed to increases in the use of willpower) were sufficient to account for the framing effect on the choice of more delayed rewards (*SI Note D*).

Valuation and willpower are challenging to disambiguate. The primary measure for most decisions is choice behavior, which can be altered by changes in valuation or willpower. Our studies and inferences would not have been possible without recent advances that allow these separate processes to be isolated using behavioral and neuroimaging methodologies (11).

How might our manipulation have changed the subjective values of immediate and delayed rewards? The explicit-zero format contains more words than the hidden-zero format and could potentially impose a greater cognitive load on decision makers. However, participants exhibited no difference in reaction times when making decisions in either presentation format, suggesting that cognitive demand was no greater for choices presented in the explicit-zero format (*SI Note D*). Moreover, increased cognitive load has been linked with more myopic decision-making (i.e., higher rather than lower rates of temporal discounting) (25, 26); participants in our studies exhibited lower rates of temporal discounting when choices were presented in the explicit-zero format. Therefore, the reframing manipulation does not appear to operate by changing cognitive load.

Alternatively, explicit-zero framing may promote self-control by leading decision makers to perceive each reward as a bundle (17). Each choice option contains one immediate and one future reward, thereby turning decision makers' attention toward both the short-term and long-term consequences of their choices, rather than letting them consider the two time ranges separately. This view is in line with a query theory account of temporal discounting (27, 28), which posits that that the reward alternative considered first (i.e., smaller-sooner vs. larger-later) becomes more likely to be selected. By making explicit the short-term and long-term consequences of each choice, decision makers must consider future as well as immediate outcomes. Indeed, priming people to think about the future causes a similar behavioral effect for monetary decisions (17) and exposing people to an aged version of themselves promotes retirement saving (29).

In our studies, participants selected between immediate and delayed monetary payments. These are ideal decisions to study because they allow parameters of the choices to be systematically manipulated. However, are the findings applicable to important real-world decisions that benefit from improved self-control, such as diet or retirement savings? We believe so, as explicit-zero framing and its incorporation of the future into current choice options suggests a feature readily translatable to other choice scenarios. For example, people can be encouraged to ask themselves, "Do I want to eat this cookie now and weigh more tomorrow, or do I want to forego this cookie now and be thinner tomorrow?" Or, "Do I want to put aside some savings now and be comfortable in the future, or do I want to spend the money now and be financially insecure in the future?" Linking the future to the present might facilitate wiser choices. We hope our findings inspire researchers, clinicians, and policy makers to embrace the viability of developing techniques that lead to greater self-control without requiring greater willpower, so that the right choice becomes the more viscerally appealing choice.

Materials and Methods

Study 1. ***Participants.*** A sample of 182 online respondents (93 females; mean age = 35.66, *SD* = 21.26) participated in exchange for monetary compensation (see *SI Note A* for exclusion criteria).

Materials. Subjective valuation of standalone rewards. Participants evaluated standalone rewards using a visual analog scale (VAS). Rewards were taken from the choice pairs (smaller-immediate and larger-delayed) used in the choice tasks, but each reward was presented individually, without referring to the other reward in the pair (*SI Note E*). Rewards were presented either in hidden-zero or explicit-zero format (hidden-zero immediate: "How happy would you feel RIGHT NOW if you were to receive $6.00 today?"; hidden-zero delayed: "How happy would you feel RIGHT NOW if you were to receive $8.50 in 46 days?"; explicit-zero immediate: "How happy would you feel RIGHT NOW if you were to receive $6.00 today and $0 in 46 days?"; explicit-zero delayed: "How happy would you feel RIGHT NOW if you were to receive $0 today and $8.50 in 46 days?"). For immediate rewards, explicit-zero delay was based on the larger option delay within the choice pair.

The VAS was bounded by two text anchors: "very happy" (top) and "not happy at all" (bottom). Values ranged from 0 to 100 and were not visible to participants.

Choice pairs and choice task. Choice pairs were constructed with rewards from the valuation task. Similarly, the same monetary values and delays were used for the hidden- and explicit-zero formats (*SI Note E*). For all choice pairs, the immediate reward was presented on the left of the screen, and the delayed reward was presented on the right of the display (*SI Note F*).

Procedure. The study was conducted online. Participants were randomly assigned to one of three groups, which determined order and format of the valuation and choice tasks (Table S1). Each reward pair was presented twice, once in hidden-zero format and once in explicit-zero format, and order was randomized and counterbalanced across participants. Before each task, participants were reminded that one of their choices, selected randomly at the end of the session, would determine their compensation (12, 13).

Study 2. ***Participants.*** Twenty-three individuals (13 females; mean age = 27.5, *SD* = 2.11) participated in exchange for monetary compensation (see *SI Note B* for exclusion criteria).

Materials: Choice Pairs. For each participant, 60 pairs of choices (30 per condition) were generated (*SI Note B*). Each pair comprised a smaller immediate reward (*M* = $9.00, *SD* = $3.97) and a larger delayed reward (*M* = $11.44, *SD* = $5.15; mean delay = 52 d, *SD* = 24.47 d).

Procedure. Functional data were collected on a 3T Siemens Trio scanner using standard acquisition protocol, with event timing selected to enable event-related analyses (*SI Note B*).

ACKNOWLEDGMENTS. We thank Anthony Wagner for helpful comments on the manuscript. This work was supported by a Russell Sage Foundation's Small Grant Program in Behavioral Economics (to E.M.) and by the John Philip Coghlan fellowship and National Institutes of Health Grant U01 HL103629 (to S.M.M.). E.M. thanks the Robert Wood Johnson Foundation Health and Society Scholars program for its financial support during the preparation of this manuscript.

1. Moffitt TE, et al. (2011) A gradient of childhood self-control predicts health, wealth, and public safety. *Proc Natl Acad Sci USA* 108(7):2693–2698.
2. Gathergood J (2012) Self-control, financial literacy and consumer over-indebtedness. *J Econ Psychol* 33(3):590–602.
3. Duckworth AL, Seligman MEP (2005) Self-discipline outdoes IQ in predicting academic performance of adolescents. *Psychol Sci* 16(12):939–944.
4. Duckworth AL, Tsukayama E, May H (2010) Establishing causality using longitudinal hierarchical linear modeling: An illustration predicting achievement from self-control. *Soc Psychol Personal Sci* 1(4):311–317.
5. Finkel EJ, Campbell WK (2001) Self-control and accommodation in close relationships: An interdependence analysis. *J Pers Soc Psychol* 81(2):263–277.
6. Tangney JP, Baumeister RF, Boone AL (2004) High self-control predicts good adjustment, less pathology, better grades, and interpersonal success. *J Pers* 72(2):271–324.
7. Gibbons FX, et al. (2012) The erosive effects of racism: Reduced self-control mediates the relation between perceived racial discrimination and substance use in African American adolescents. *J Pers Soc Psychol* 102(5):1089–1104.
8. Magen E, Gross JJ (2010) *Handbook of Personality and Self-Regulation*, ed Hoyle RH (Wiley-Blackwell, New York).
9. Ainslie G (2001) *Breakdown of Will* (Cambridge Univ Press, Cambridge, UK), 1st Ed.
10. Hare TA, Camerer CF, Rangel A (2009) Self-control in decision-making involves modulation of the vmPFC valuation system. *Science* 324(5927):646–648.
11. Figner B, et al. (2010) Lateral prefrontal cortex and self-control in intertemporal choice. *Nat Neurosci* 13(5):538–539.
12. McClure SM, Laibson DI, Loewenstein G, Cohen JD (2004) Separate neural systems value immediate and delayed monetary rewards. *Science* 306(5695):503–507.
13. Kable JW, Glimcher PW (2007) The neural correlates of subjective value during intertemporal choice. *Nat Neurosci* 10(12):1625–1633.
14. Peters J, Büchel C (2011) The neural mechanisms of inter-temporal decision-making: understanding variability. *Trends Cogn Sci* 15(5):227–239.
15. Crockett MJ, et al. (2013) Restricting temptations: Neural mechanisms of precommitment. *Neuron* 79(2):391–401.
16. Magen E, Dweck CS, Gross JJ (2008) The hidden-zero effect: Representing a single choice as an extended sequence reduces impulsive choice. *Psychol Sci* 19(7):648–649.
17. Radu PT, Yi R, Bickel WK, Gross JJ, McClure SM (2011) A mechanism for reducing delay discounting by altering temporal attention. *J Exp Anal Behav* 96(3):363–385.
18. Ochsner KN, Gross JJ (2008) Cognitive emotion regulation: Insights from social cognitive and affective neuroscience. *Curr Dir Psychol Sci* 17(2):153–158.
19. Hutcherson CA, Plassmann H, Gross JJ, Rangel A (2012) Cognitive regulation during decision making shifts behavioral control between ventromedial and dorsolateral prefrontal value systems. *J Neurosci* 32(39):13543–13554.
20. Bickel WK, Yi R, Landes RD, Hill PF, Baxter C (2011) Remember the future: Working memory training decreases delay discounting among stimulant addicts. *Biol Psychiatry* 69(3):260–265.
21. Job V, Dweck CS, Walton GM (2010) Ego depletion—Is it all in your head? Implicit theories about willpower affect self-regulation. *Psychol Sci* 21(11):1686–1693.
22. Thaler RH, Benartzi S (2004) Save more tomorrow: Using behavioral economics to increase employee saving. *J Polit Econ* 112(1, Pt 2):S164–S187.
23. Choi JJ, Laibson D, Madrian BC, Metrick A (2005) . *Saving for Retirement on the Path of Least Resistance* (Rodney L White Cent for Financial Res, Philadelphia), Working Pap 9.
24. Robinson TN (2010) Save the world, prevent obesity: Piggybacking on existing social and ideological movements. *Obesity (Silver Spring)* 18(Suppl 1):S17–S22.
25. Bickel WK, Yi R (2008) Temporal discounting as a measure of executive function: Insights from the competing neuro-behavioral decision system hypothesis of addiction. *Adv Health Econ Health Serv Res* 20:289–309.
26. Shiv B, Fedorikhin A (1999) Heart and mind in conflict: The interplay of affect and cognition in consumer decision making. *J Consum Res* 26(3):278–292.
27. Weber EU, et al. (2007) Asymmetric discounting in intertemporal choice: A query-theory account. *Psychol Sci* 18(6):516–523.
28. Appelt KC, Hardisty DJ, Weber EU (2011) Asymmetric discounting of gains and losses: A query theory account. *J Risk Uncertain* 43(2):107–126.
29. Hershfield HE, et al. (2011) Increasing saving behavior through age-progressed renderings of the future self. *J Mark Res* 48:S23–S37.