Materials and Methods for OpenfMRI ds009: The generality of self control

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1 Materials and Methods

1.1 Participants.

89 healthy adults were recruited from UCLA's campus via posted advertisements for a behavioral study exploring the relationship between different forms of self-control. Participants were eligible if they were between the ages of 18 and 40, right-handed, not currently taking psychoactive medication or illegal substances, had no history of neurological illness, and had a social security number (necessary for payment, see below). Of these participants, 11 were excluded because of: incomplete data (7) or poor performance defined a priori for each task (4). The remaining 78 participants had a mean age of 21.3 (range 18-34) and there were 39 females. Each of these 78 participants was invited back to participate in the MRI study if they were eligible to participate in an MRI scan (i.e., not claustrophobic, not pregnant, and no metal in their bodies). Of these 78, 29 participated in the MRI study. Five participants were excluded because of: technical issues (2; artifacts due to a loose head coil and field of view did not cover the entire brain) or poor behavioral performance defined a priori for each task (3). Therefore, 24 participants with a mean age of 20.8 (range 18-33, 10 females) were included in the MRI study. All participants provided written informed consent according to the procedures of the UCLA Institutional Review Board.

1.2 Experimental Design and Procedure.

Stop-Signal: Behavioral participants performed three runs of the SS task (Logan, Dagenbach, & Carr, 1994) and MRI participants performed two more during MRI scanning. The primary task was a simple two-choice reaction time task with spatially compatible stimulus-response mappings. On go trials, participants pressed the right button with their right middle finger if an arrow pointed rightwards and the left button with their right index finger if the arrow pointed leftwards. On each go trial, an open circle appeared on the computer monitor for 500 ms to indicate that the primary stimulus was about to appear (visual angle subtended 4.9 x 4.9). Then the arrow, pointing left or right, appeared in the

center of the circle until the participant responded or 1000 ms elapsed. The duration of the blank screen between the trials was 500 ms for the behavioral version and was jittered between 500 and 4000 ms (mean 1000 ms, sampled from an exponential distribution) for the MRI version so as to optimize our ability to compare successful inhibition trials to go trials with fMRI.

On 25% of the trials, a tone was sounded (stop trials) and participants tried to inhibit their already initiated response to the arrow. The tone was presented at varying delays (the stop-signal delay; SSD) after the onset of the go stimulus. If participants responded on a stop trial, the trial proceeded as if it were a go trial. If participants inhibited their response, the arrow remained on the screen for 1000 ms, followed by the jittered interval between trials (Figure 1).

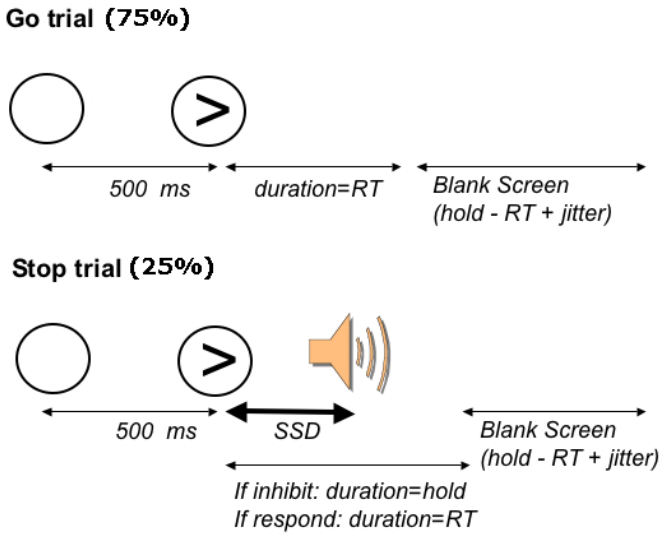

Figure 1: Schematic of go and stop trials on the stop-signal task. Timing reflects that of the MRI version.

An adaptive, tracking staircase procedure was used to adjust the SSD at which the presentation of the stop-signal resulted in approximately 50% inhibition of responses. Two independent staircase functions with a step size of 50 ms were used to determine SSD. Starting delays for the two ladders on the first run of the stop-signal task were 250 ms and 350 ms respectively. The delay of each staircase was increased by 50 ms if a participant successfully inhibited his or her response to make it more difficult to inhibit a response on the next stop trial. If a participant responded on a stop trial, however, the delay was decreased by 50 ms to make it easier to inhibit a response on the next stop trial. For each subsequent run, the last SSD of each staircase on the previous block was used as each staircase's starting value. By using a dynamic SSD, we ensured that each participant was

able to successfully inhibit his or her responses on approximately 50% of the stop trials. The two staircases began at slightly different delays in order to maximize the chance that at least one would begin close to a participant's ideal SSD.

Each run had 128 trials: 96 go trials and 32 stop trials and lasted between 352 and 362 seconds, depending on the length of the jittered inter-trial intervals. For each eight trials, there were four left arrows and four right arrows. There were also two stop trials (one for each ladder). Order of arrow direction, stop-trial ladder, and on which trials the stop-signal occurred were randomized. For behavioral trials there were four different list orders and for MRI trials each participant had a unique list order to ensure that there were no order effects.

BART: Behavioral participants performed one run of the BART (Lejuez et al., 2002) and MRI participants performed one additional run during MRI scanning. Participants saw a balloon on the monitor and were given the option to either inflate it by pressing the left button with their right index finger or to stop inflating it by pressing the right button with their right middle finger. For the behavioral version, the balloon began at a value of 5 cents and each pump of the balloon added one cent to a temporary pool of winnings. For the MRI version, the balloon began at a value of 50 cents and its value was increased by 25 cents for each pump. If the participant decided to stop inflating the balloon, the accrued money was moved to a permanent store of winnings and a new balloon was presented. After a variable number of pumps the balloon exploded, in which case the participant lost all the money in the temporary pool. The actual number of pumps before an explosion followed a uniform distribution across trials, with an average of 32 pumps for the behavioral version (SD = 10 pumps) and 6 pumps for the MRI version (SD = 2 pumps). There were two balloon colors for the behavioral version (blue and red) and only one for the MRI version (blue). Each balloon color was presented 36 times for a total of 72 trials for the behavioral version and 36 trials for the MRI version.

The number of trials and the average number of pumps before explosion varied between the behavioral and MRI versions because the timing for each version was quite different from that of the other. For the behavioral version, the balloon remained on the monitor until the participant made a choice. If the choice was to inflate the balloon, the next balloon appeared after 100 ms. After each pump, the balloon size increased by 2%. If the balloon exploded, after a delay of 100 ms the participant saw an image of an exploded balloon for 1500 ms, along with the amount of money won so far. If the participant chose to cash out and stop inflating the balloon, the balloon remained on the screen with the updated amount of money earned for 1500 ms. The next trial began after a delay of 500 ms. There were two brief breaks during the behavioral version.

For the MRI version, the balloon once again remained on the monitor until the participant made a choice. The time between events was longer than during the behavioral version and variable so we could pull apart neural responses to each of the event types. If the choice was to inflate the balloon, the next balloon appeared after a jittered delay of between 1000 ms and 3000 ms (mean 2000 ms, uniform distribution). After each pump,

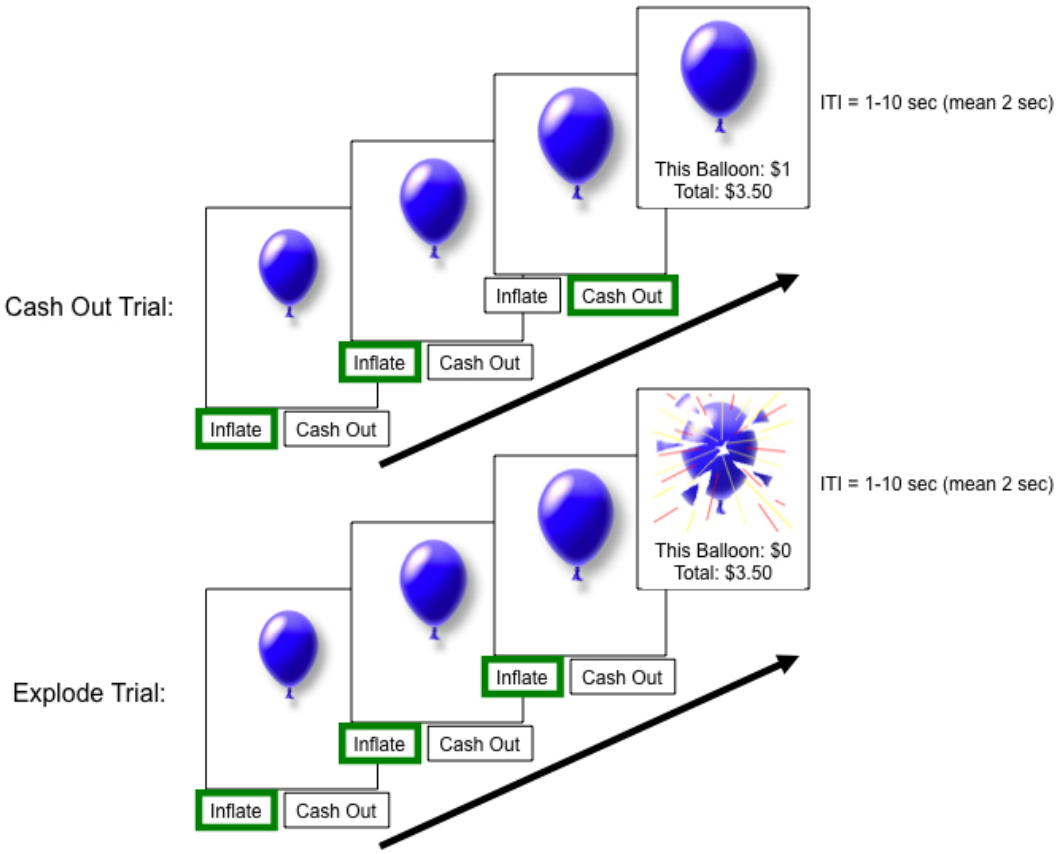

Figure 2: Example of a cash out trial and an explode trial on the balloon analogue risk task. Timing reflects that of the MRI version.

the balloon size increased by 15%. If the balloon exploded, after a jittered delay from the same distribution as used when inflating the balloon, the participant saw an image of an exploded balloon for 2000 ms, along with the amount of money won so far. If the participant chose to cash out and stop inflating the balloon, the balloon remained on the screen with the updated amount of money earned for 2000 ms. The next trial began after a jittered delay of between 1000 ms and 12000 ms (mean 2000 ms, exponential distribution). Run length was variable for this task since it was based on participant responses, but the maximum length was capped at 600 seconds (mean = 500 seconds [SD = 30 seconds]; Figure 2).

Participants received the actual amount of money earned during this task in order to ensure that they took the task seriously and viewed pumping the balloon as risky.

Temporal Discounting: Behavioral participants performed one run of the TD task (Kable & Glimcher, 2007; McClure, Laibson, Loewenstein, & Cohen, 2004) and MRI par-

ticipants performed one additional run during MRI scanning. Participants made a series of decisions regarding whether they would prefer to receive a smaller amount of money immediately or a larger, variable amount of money after a variable delay. For all trials, the two payment/delay options were presented adjacent to each other on the computer monitor and participants were instructed to press the left of two buttons with their right index finger if they preferred the option displayed on the left of the monitor (the immediate option) and to press the right button with their right middle finger if they preferred the option displayed on the right of the monitor (the delayed option). The behavioral and MRI versions were very different from each other because we took advantage of learning about the individual discounting parameter for each participant during the behavioral version to determine the choices presented during the MRI version.

For the behavioral version, the immediate amount was either $5 or $10. There were six possible delays (2 days, 1 week, 3 weeks, 2 months, 4 months & 1 year). The delays were evenly distributed along a log scale then adjusted to give delays that would be easily interpreted (i.e., 2 months instead of 71 days). The dollar amount of the delayed option ranged from $5 to $120 and was determined adaptively with a staircasing procedure (Du, Green, & Myerson, 2002; Estle, Green, Myerson, & Holt, 2007). Based on previous literature, it was assumed that each participant's pattern of discounting the value of the delayed option followed a hyperbolic curve (Kable & Glimcher, 2007; Monterosso et al., 2007). The parameter describing the steepness of the curve (k; discounting parameter) has an average value of approximately 0.013 based on previous results from studies in healthy adults (Kable & Glimcher, 2007; Kirby, Petry, & Bickel, 1999; Monterosso et al., 2007). Assuming a hyperbolic discounting function, the equation to determine the subjective value of a delayed option is:

$$SV = V/(1 + kD)$$

where SV = the subjective value of the payment after accounting for its discounted value, V = the numerical value of the payment, k = the individual's discounting parameter, and D = the delay in days of the payment. We calculated the indifference point of each option, where the subjective value of the delayed amount was equal to the actual value of the immediate amount; this would result in an option where a person with the same discounting parameter would feel that the two options were equivalent. This allowed us to calculate the actual value of the delayed amount given the delay and the immediate amount:

$$V = SV * (1 + kD)$$

where SV is equal to the immediate amount on any given trial. There were 96 adaptive trials: 50% with each immediate value ($5 and $10) and 8 occurrences of each delay for each starting value. The order of trials was random. The task began by assigning a k-value of 0.013 (the average in the healthy adult population) to each of two staircases, one

assigned to all immediate $5 options and a second assigned to all immediate $10 options. A combination of the k-value, the delay, and the immediate amount was used to determine the delayed amount presented to the participant. The only constraint to this approach was that the maximum delayed amount was capped at $120. After each trial, the k-value was updated based on the QUEST toolbox in MATLAB (A. B. Watson & Pelli, 1983). The QUEST parameters were as follows: starting estimate (0.013), standard deviation (.02), probability of choosing delayed (0.5), Weibull function parameters (beta = 5, delta = 0.01, gamma = 0.01), step size (0.001), and range of responses (1). If a participant chose the immediate amount, the indifference k-value on that trial was smaller than the person's actual k-value and it was increased on the next trial. If a participant chose the delayed amount, the indifference k-value was decreased on the next trial. This procedure was used so that the staircases would converge at the person's indifference k-value by the end of the run. Order of immediate amount and delay was random. As a check of this adaptive procedure, 54 trials with a set indifference k-value were randomly interspersed throughout the task. There were nine pre-defined k-values (.005, .0075, .01, .02, .03, .04, .05, .075, .1; Kirby et al., 1999). Each k-value was tested once per delay and randomly assigned to a starting value of $5 or $10, since pilot testing showed no difference between the converged k-values for the two starting values. Order of k-value, delay, and immediate amount was random. This allowed us to compare the k-values determined through the adaptive and through the set method, which were highly correlated ($r = 0.89$, $p < .00001$). The means of the two values were not significantly different from each other ($t(76)=0.95$, $p = .3$). Two different list orders were used to ensure that there were no order effects.

Each choice was displayed to participants until a choice was made or 8000 ms. After 3000 ms if no response was made, a prompt appeared underneath the options to remind participants to respond. After the choice was made, a fixation crosshair was displayed for 1000 ms before the next trial began. There was one brief break in the middle of the run.

For the MRI version, we took advantage of having an estimate of each participant's discounting parameter (k). We defined trials as hard or easy based on each person's previously estimated indifference k-value. Hard trials gave choices that were only a small amount different from the indifference delayed amount (1% or 5%). Easy trials gave choices that were quite different from the indifference delayed amount (95%, 99%, 190%, or 200%). The same immediate amounts and delays were used as in the behavioral version. There were 96 trials. For each of the two immediate values each delay was tested 8 times at different degrees of difficulty. For each immediate value/delay combination, there were two hard amounts that were less than the indifference delayed amount (1% and 5%; hard immediate), two hard amounts that were more than the indifference delayed amount (1% and 5%; hard delayed), two easy amounts that were less than the indifference delayed amount (95% and 99%; easy immediate), and two easy amounts that were more than the indifference delayed amount (190% and 200%; easy delayed). Note that for the easy amounts the percent change was different for easy immediate and easy delayed trials. This is because if the easy immediate amount was more than 100% less than the indifference

value, then the delayed amount could be less than the immediate amount. We constrained the minimum delayed amount so it could be no less than the immediate amount. Trial order was generated using an m-sequence (Liu, 2004; Liu & Frank, 2004), a pseudorandom sequence optimized to maximize the tradeoff between power and efficiency, with 13 trial types (6 delays x hard vs. easy + null events). Because no differences were seen between immediate values of $5 or $10, order of those was pseudorandom, constrained so that 50% of hard immediate, 50% of hard delayed, 50% of easy immediate, and 50% of easy delayed had immediate values of $5 and 50% of each had immediate values of $10. Four different list orders were used to ensure that there would not be order effects.

At the beginning and end of the task a fixation crosshair was displayed on the screen for 16 seconds to get a baseline comparison. Each choice was displayed to participants for 4500 ms regardless of when they made their choice. There was a fixation crosshair between trials for 750 ms. There were eight null events (fixation crosshair) with a duration of 5250 ms randomly interspersed throughout the task. The run lasted 580 seconds (Figure 3).

Figure 3: Example trial on the temporal discounting task. Timing reflects that of the MRI version.

Participants received the actual amount of money at the delay chosen for one randomly selected trial on this task (with the delayed amount capped at $120) to ensure that they took the task seriously. Participants were briefed on the payment procedure before the task and all stated in a debriefing questionnaire after the study that they believed it would occur as explained.

Emotion Regulation: Behavioral participants performed one run of the ER task (Ochsner et al., 2004) and MRI participants performed two additional runs during MRI scanning. Before the task, participants were trained on the technique of cognitive reappraisal to

teach them how to reduce their negative affect when viewing aversive images. Cognitive reappraisal involves redefining the image in a non-emotional, less negative manner and has been used successfully in previous studies to reduce negative affect (Gross, 1998, 2002; Ochsner, Bunge, Gross, & Gabrieli, 2002; Ochsner et al., 2004; Phan et al., 2005). For example, an image of a person with a gruesome bullet wound may be described as an actor in a movie where the person is covered in fake blood. Participants were trained until they understood the concept of cognitive reappraisal and were able to successfully reappraise aversive images without the help of the experimenter.

Participants saw 60 novel images from the International Affective Picture System (IAPS; Lang, Greenwald, Bradley, & Hamm, 1993). 20 images were neutral and 40 were aversive. IAPS images are rated on a 9-point likert scale for both valence and arousal, with most unpleasant and least arousing corresponding to the lowest ratings. Neutral images were chosen from those rated between 4.38 and 6.53 for valence (mean = 5.03 [SD = 0.50]) and 1.72 and 3.85 for arousal (mean = 2.81 [SD = 0.42]). Negative images were rated between 1.31 and 4.60 for valence (mean = 2.36 [SD = 0.76]) and 4.45 and 7.35 for arousal (mean = 5.93 [SD = 0.79]). There were two instruction conditions in this experiment: suppress and attend. In the suppress condition, participants were instructed to attempt to suppress any negative emotions they may feel using cognitive reappraisal. Crucially, participants were told not to take their eyes off the images or to distract themselves with irrelevant thoughts. During attend trials, participants were instructed to look at the images and respond naturally. 20 trials were attend to neutral images (attend neutral trials), 20 were attend to negative images (attend negative trials), and 20 were suppress to negative images (suppress negative trials). Trial order was randomized for the behavioral version and optimized to detect differences in BOLD response to suppress negative trials as compared to attend negative trials for the MRI version. Average IAPS image ratings were equivalent for the behavioral and MRI runs for each participant, as were the average ratings for the attend negative images and the suppress negative images within each run (ANOVA comparing suppress negative and attend negative for behavioral and MRI runs: $F(3,76) = .02$, $p > .99$ for valence and $F(3,76) = .004$, $p > .99$ for arousal; t-test comparing attend neutral images between the behavioral and MRI runs: $t(38) = .49$, $p = .63$ for valence and $t(38) = .03$, $p = .98$ for arousal). Each group of images contained 50% faces and 50% non-faces. There were four different list orders, each containing a different combination of images, to ensure that there were no order effects.

During the task, each trial began with the instructions for that trial (suppress or attend) displayed for 1 second. Participants were instructed to view the images as they were for the "attend" trials and utilize cognitive reappraisal for the "suppress" trials. They then viewed the image (either aversive or neutral) for 5 seconds. There was then a fixation crosshair for 2 seconds, followed by a self-report screen for 3 seconds, which asked the participants how negative they felt after either suppressing or attending to the image on a 4-point likert scale from 1 (very slightly or not at all negative) to 4 (extremely negative). The trial ended with a 3 second fixation crosshair before the next trial began. The only difference between the

behavioral and MRI versions was that the behavioral version was one run with two brief breaks, whereas the MRI version was separated into two runs of 392 seconds each (Figure 4). Before and after the task, participants were administered the Positive and Negative Affect Schedule (PANAS; D. Watson, Clark, & Tellegen, 1988), which asks people to report the extent to which they are currently experiencing 20 emotions in order to assess changes in mood. After the MRI scan, MRI participants viewed all images they had seen during the scan and rated the negativity of each one (when attending to the image) on a 7-point likert scale from 1 (not at all negative) to 7 (extremely negative).

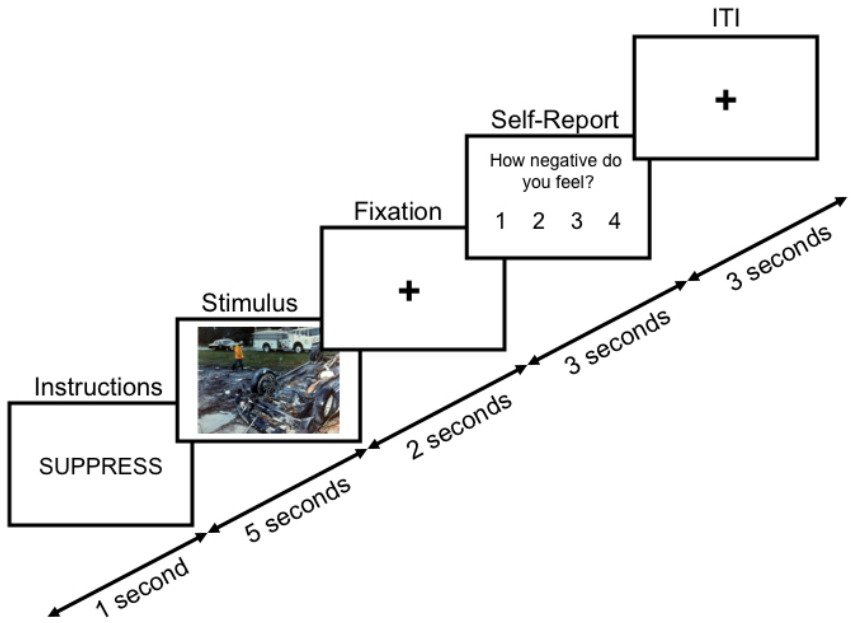

Figure 4: Example of a suppress trial on the emotion regulation task. Attend trials had an identical timecourse.

In order to minimize demand characteristics, participants were instructed before the task that emotion regulation is not always successful and that we specifically chose difficult images so they may not always be able to suppress their negative emotions. It was emphasized that they should rate the strength of their negative emotion honestly and not worry about whether they were successful in decreasing their negative emotions.

The MATLAB (The MathWorks, Inc., Natick, MA) Psychophysics Toolbox (Brainard, 1997) version 7.5 was used to present the stimuli to participants and to record their responses for all tasks.

Self-Report Questionnaires: A battery of pen and paper self-report questionnaires was

administered to behavioral participants to tap the presence or absence of various aspects of self-control, including impulsivity, behavioral inhibition, and risky behavior. The following questionnaires were administered (all questionnaires included in full form in appendix). The Barratt Impulsiveness Scale, Version 11 (BIS-11; Patton, Stanford, & Barratt, 1995) measures one's overall level of impulsivity along three dimensions (attention, motor, and non-planning) in 30 items. The Behavioral Inhibition/Approach Scale (BIS/BAS; Carver & White, 1994) measures one's tendency to avoid (inhibit) or approach various situations in 20 items. Approach behaviors cover three dimensions: reward responsivity, fun seeking, and drive. The Cognitive Appraisal of Risky Events (CARE; Fromme, Katz, & Rivet, 1997) measures one's perception of the positive and negative consequences of engaging in certain risky events, as well as how likely one is to engage in such events in 34 items. The Domain-Specific Risk Taking (DOSPERT; Blais & Weber, 2006; Weber, Blais, & Betz, 2002) measures one's perceived risk of, benefit of, and likelihood of engaging in risky events in 30 items. The Sensation Seeking Scale (Zuckerman, Eysenck, & Eysenck, 1978) measures how much one enjoys participating in risky events in 40 items. The Need for Cognition (Cacioppo, Petty, & Kao, 1984) measures the extent to which people prefer situations where they must think and challenge themselves in 18 items. The Gambling Attitudes and Beliefs Survey (GABS; Breen & Zuckerman, 1999) measures the extent to which one enjoys gambling and is superstitious while gambling in 35 items. The Cognitive Reflection Task (Frederick, 2005) asks participants to solve three problems in which the intuitive answer is not accurate. Participants record their answer, rate the likeliness that it is accurate, and note if they had seen the problem before.

Procedure: Behavioral participants took part in two sessions separated by 2-3 weeks and MRI participants did a third MRI session 1-9 months later (mean = 4.5 months [SD = 1.4 months]). During the first behavioral session, which lasted 60-90 minutes, participants were consented then shown examples of the negative images they would see during the emotion regulation task to ensure that they would be able to view aversive images. Next, they were given one run of the stop-signal task for practice. The session ended with the participants completing the self-report questionnaires.

The next session was 2-3 weeks later to allow time for the prepaid debit cards, which were used for payment, to be ordered and received for each participant. It lasted approximately two hours. During this session, the participant performed the four behavioral tasks, filled out debriefing questionnaires about strategy for each task, and were paid.

If a participant consented to take part in the MRI session as well, they returned 1-9 months later for their scan. They were given a urine screen to ensure that they had not used any illegal substances or alcohol before the scan. During the scan, they were administered the MRI versions of the four self-control tasks, along with structural scans to register the data. Participants viewed the tasks through LCD goggles and responded using an MR-compatible button box. After the scan, they were asked to rate the negativity of each of the images they observed during the emotion regulation task, filled out debriefing questionnaires for each task, and were paid.

Payment Procedure: Participants were paid $10/hour to fill out the self-report questionnaires and paid based on task performance on the BART and TD tasks for the other sessions, ensuring that they received at least $10/hour for the behavioral session and $20/hour for the MRI session. They were paid the total amount of money they earned on the BART and their choice for one trial chosen at random from the TD task. Participants were paid separately for performance on the behavioral version of the tasks and the MRI version of the tasks. In order to make the payment cost equivalent for choosing the delayed or the immediate option on the TD task, participants were paid with prepaid debit cards. Therefore, if they chose $5 or $10 immediately on the trial chosen as payment for the TD task, they had that amount on the card the day they participated. If they chose a larger, delayed amount, that amount was added to the same debit card on the date they were to receive their payment. BART payment was done through a combination of money on the card and cash the day of participation to ensure they were paid the appropriate amount. To order cards for people, we had to provide their name, birth date, and social security number to the prepaid debit card company.

1.3 fMRI Data Acquisition.

Imaging data were collected with a 3T Siemens Trio scanner at the Ahmanson-Lovelace Brain Mapping Center at the University of California, Los Angeles. For each functional run we collected T2*-weighted echoplanar images (34 slices, slice thickness 4 mm, TR = 2000 ms, TE = 30 ms, flip angle = 90 °, matrix 64 x 64, field of view 192 mm). A T2-weighted matched-bandwidth high-resolution anatomical scan with the same slice prescription as the functional images was also acquired. Lastly, a magnetization-prepared rapid-acquisition gradient echo (MPRage; 176 sagittal slices, slice thickness 1 mm, TR = 1900 ms, TE = 2.26 ms, matrix 256 x 256, field of view 250) was collected.

1.4 Behavioral Data Analysis.

Stop-Signal: Go task response time (RT) and accuracy, percent successful inhibition, average SSD, and SSRT were calculated for each participant. Only correct go trials were included in the go RT analyses. SSRT was calculated according to the race model of stopping (Logan & Cowan, 1984). The race model assumes that the go and stop processes occur in parallel and are stochastically independent (although when using the tracking method this assumption is not critical; see: Band, van der Molen, & Logan, 2003). The go process begins when the go task stimulus appears on the screen and ends with the participant's response, which falls within an RT distribution. The stop process begins when the stop-signal occurs and ends after a duration termed the stop-signal reaction time (SSRT) that is assumed to be constant. This is a measure of the time it takes for a participant, once hearing the tone, to be able to suppress his or her response (Logan et al., 1994). The two processes are in a race; whichever finishes first determines the outcome of the trial.

To calculate SSRT, first all correct RTs were arranged in an assumption-free distribution in ascending order. Then the proportion of failed inhibition (i.e., the proportion of stop trials on which the participant responded) was determined. The RT corresponding to that proportion was computed (i.e., if failed inhibition was .55, the RT corresponding to 55% of the area under the RT distribution curve): the quantileRT. SSRT was calculated as the difference between the quantileRT and the average SSD.

BART: Average number of pumps for each balloon, number of exploded balloons, and amount of money won across the run were calculated for each participant. For the behavioral version with two balloon colors, the three variables were calculated separately for each balloon color and then averaged.

Temporal Discounting: The steepness of each participant's discounting curve (k-value) was calculated. For the behavioral version, if the participant's adaptive k-staircases converged, the average of the 10 steps of the ladder around the convergence point was taken. If the staircases did not converge (9 of 78 participants), the k-value from the set k trials was calculated (Kirby et al., 1999). The geometric means between each two consecutive tested k-values, plus the lowest and highest tested k-values, were the possible k-values a participant could have. Each mean was given a point if a participant responded consistently with that k-value (i.e., k-values higher than the indifference k on an immediate choice or lower than the indifference k on a delayed choice were considered consistent). The mean with the highest number of points was considered the participant's actual k-value. If there was more than one, the geometric mean of all options with the same number of points was taken. For the MRI version, logistic regression was used to calculate each participant's k-value.

Emotion Regulation: Amount of reported regulation was calculated for participants by subtracting the average of their rating scores after all the suppress negative images from the average of their rating scores after all the attend negative images.

Behavioral Relationships: In order to determine whether there were any relationships in behavioral performance across tasks or between task performance and self-reports on the questionnaires, we conducted a series of Pearson correlations between variables of interest.

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