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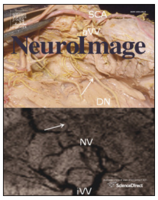

When “Your” reward is the same as “My” reward: Self-construal priming shifts neural responses to own vs. friends' rewards

Michael E.W. Varnum [a,*], Zhenhao Shi [b,c], Antao Chen [d], Jiang Qiu [d], Shihui Han [b,c,**]

[a] Department of Psychology, Arizona State University, Tempe, AZ 85287, USA
[b] Department of Psychology, Peking University, Beijing, China
[c] PKU-IDG/McGovern Institute for Brain Research, Peking University, Beijing, China
[d] Faculty of Psychology, Southwest University, Beibei, Chongqing, China

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ABSTRACT

Is it possible for neural responses to others' rewards to be as strong as those for the self? Although prior fMRI studies have demonstrated that watching others get rewards can activate one's own reward centers, such vicarious reward activation *has always been less strong* than responses to rewards for oneself. In the present study we manipulated participants' self-construal (independent vs. interdependent) and found that, when an independent self-construal was primed, subjects showed greater activation in the bilateral ventral striatum in response to winning money for the self (vs. for a friend) during a gambling game. However, priming an interdependent self-construal resulted in comparable activation in these regions in response to winning money for the self and for a friend. Our findings suggest that interdependence may cause people to experience rewards for a close other as strongly as they experience rewards for the self.

Introduction

Vicarious reward, a sense of pleasure derived from watching others gain rewards, has been implicated in a number of basic processes from altruism (Ainslie, 1995) to learning (Bandura, 1977). The experience of vicarious reward may also be a psychological mechanism that is necessary for the evolutionary process of kin selection to occur (Campbell-Meiklejohn and Frith, 2012; Mobbs et al., 2009). Although vicarious reward has been described as “a raw feel, as robust as food or pain”, (Ainslie, 1995, p. 395), no evidence suggests that people experience others' rewards as strongly as they experience those same rewards directly. In fact, a review of the neuroimaging literature failed to find any published study in which vicarious rewards produced equal or stronger activation in the reward network than rewards for the self.

That said, there have been a handful of functional magnetic resonance imaging (fMRI) studies that have demonstrated that social factors can modulate vicarious reward. For example, Mobbs et al. (2009) found that people show greater activation in the ventral striatum (VS) when watching socially desirable others (as opposed to socially undesirable others) win at a card-guessing game. In addition, connectivity between the VS and the anterior cingulate cortex (ACC) while watching others' win was positively correlated with perceived similarity between oneself and the target. In another study in which participants played a card-guessing game where they shared their rewards either with a friend, a stranger, or a computer, Fareri et al. (2012) found greater VS activation in response to winning rewards when their partner was a friend, though this effect was confined to participants who were high in subjective closeness to that friend.

Given that similarity and closeness to the other party appear to strengthen neural response to vicarious reward, perhaps if subjects are induced to construe the self in an interdependent fashion (that is interconnected with and encompassing close others) as opposed to an independent fashion (that is autonomous and bounded; Markus and Kitayama, 1991; Varnum et al., 2010) then vicarious reward and reward for the self might produce comparable activation in neural regions involved in reward. fMRI studies have demonstrated comparable activation in the medial prefrontal cortex (mPFC) involved in representation of one's own traits and a close other's traits in a society where interdependent self-construal is common (Zhu et al., 2007), and that priming interdependence has a similar effect (Chiao et al., 2010; Ng et al., 2010). Here we tested whether vicarious reward and reward for the self might produce comparable activation in the neural regions involved in reward when interdependence is primed.

The present study tested the prediction that priming an interdependent self-construal will lead to equal response to rewards for the self and a friend, whereas priming an independent self-construal would lead to greater responses to own rewards vs. a friend's rewards. Given the fact that previous research on reward has consistently shown that

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* Correspondence to: M.E.W. Varnum, Department of Psychology, Arizona State University, 950 S. McAllister, Tempe, AZ 85287, USA.
** Correspondence to: S. Han, Department of Psychology, Peking University, Beijing 100871, China.
E-mail addresses: mvarnum@asu.edu (M.E.W. Varnum), shan@pku.edu.cn (S. Han).

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the VS responds to rewards for the self (e.g. Bjork and Hommer, 2007; Delgado et al., 2000; Fareri et al., 2012; Mobbs et al., 2009; O'Doherty et al., 2003) and to vicarious rewards (Fareri et al., 2012; Mobbs et al., 2009), we predicted that this effect would be present in the VS.

Methods

Participants

Fifteen students from Southwest University (after excluding 4 participants with excessive motion; age ranging from 19 to 24, 10 females) participated in the main study. An independent sample of 16 students (age ranging from 18 to 25, 9 females) participated in the localizer study. All were Chinese, right-handed, had normal or corrected-to-normal vision, and reported no abnormal neurological or psychiatric history. Participants provided informed consent, and the study was approved by a local ethics committee.

Stimuli and procedure

All materials were presented in Chinese. For the main study, 10 pairs of sex-matched friends were recruited for the main study. The two friends that comprised each pair were scanned successively (except for one participant whose friend, unbeknownst to her until the completion of the study, was precluded from scanning due to a metal implant). That is, participants actually believed that their friend was also participating in the study (and with one exception this was the case). Participants were told that the study involved a card-guessing game, and that they would have a chance to win extra monetary rewards for themselves and their friends in addition to their basic payment (CNY ¥70, ≈USD $11.2). Adapting our procedure from Delgado et al. (2000), each trial of the card-guessing game began with a 2-second presentation of a "?" in the center of a card against a black background, during which the participant guessed whether the number on the card would be smaller or greater than 5 by pressing the left or right button using her right index or middle finger. The number on the card was then revealed by replacing the cue with one of the following numbers: "1", "2", "3", "4", "6", "7", "8", and "9". The number was colored green if the participant had made a correct guess and red if the guess was incorrect. A correct guess resulted in a monetary reward of CNY ¥1.00 (≈USD $0.16), and an incorrect one resulted in a loss of CNY ¥0.50 (≈USD $0.08) (Outcome: Win/Loss). Simultaneously, a square or rhombus was shown below the number to indicate that the participant had won or lost for either herself or her friend (Target: Self/Friend). Unbeknownst to participants, the game was programmed so that there would be an equal number of win and loss trials for the self and one's friend in all conditions. We also included neutral trials (not linked to monetary outcomes) in which only the letter "N" was presented (Fig. 1). All characters were presented at a distance of 25 cm subtending a visual angle of 1.12° × 1.12°. After each trial, the outcome was followed by a fixation cross which was presented for 8 s before the next trial. The main study involved 8 functional runs of the card-guessing game. Each run contained 25 randomly ordered trials consisting of 5 trials of each of the following outcomes: Self Win, Self Loss, Friend Win, Friend Loss, as well as 5 neutral trials.

For approximately half of participants ($N = 8$, 6 female), each of the first 4 runs was immediately preceded by independent self-construal priming, and each of the last 4 runs was preceded by interdependent self-construal priming (Prime: Independent/Interdependent); for the other participants the priming order was reversed. Each prime consisted of 16 sentences that made up a short story about traveling. Following a similar procedure as in Sui and Han (2007), participants judged whether pronouns were present in sentences containing first-person singular pronouns in the independent priming condition (e.g., 'I lay on the chair and relaxed with my eyes closed'), or first-person plural pronouns in the interdependent condition (e.g., 'We lay on the chairs and had a chat'). Each sentence was shown on the screen for 5 s and followed by a "?" for 1 s during which participants pressed the left or right button to indicate the presence of the pronoun.

At the conclusion of the main study, participants were debriefed and paid CNY ¥90 (≈USD $14).

After scanning, participants completed a measure of the degree of closeness they felt to their friend (adapted from Aron et al., 1992), the Self-Construal scale (SCS; Singelis, 1994), and the Horizontal and Vertical Individualism and Collectivism scale (HVIC; Triandis and Gelfand, 1998). They also completed four 7-point Likert scales (−3: very unhappy; 3: very happy) to indicate how happy they felt when they/their friends won/lost rewards.

A localizer study served to pre-localize the loci of the bilateral VS that encode monetary reward. Participants were scanned for two functional runs while playing the same game used in the main study, except that they played only for themselves and no priming was administered. In addition to their basic payment CNY ¥20 (≈USD $3.2), they had a chance to win CNY ¥2.00 (≈USD $0.32) or lose CNY ¥1.00 (≈USD $0.16) on each trial. Each run contained 10 Win trials, 10 Loss trials, and 10 Neutral trials. After scanning, participants completed the SCS and the HVIC. At the conclusion, they were debriefed and paid CNY ¥40 (≈USD $6.4).

fMRI data acquisition and analysis

Scanning was performed using a 3T Siemens TRIO MRI scanner. Gradient-echo T2*-weighted echo-planar images (EPI) covering the

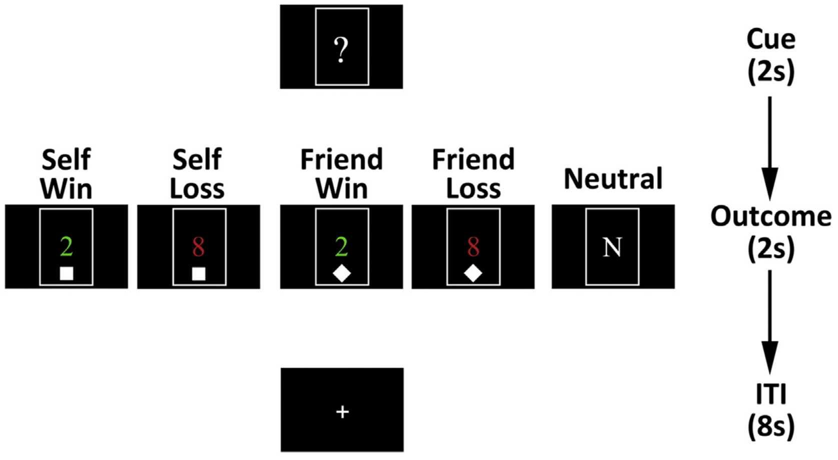

Fig. 1. Trial structure. ITI: inter-trial interval.

whole brain were acquired using the following parameters: 64 × 64 ×32 matrix with 3.75 × 3.75 × 5 mm^3 spatial resolution, inter-slice gap = 1 mm, field of view (FOV) = 24 × 24 cm^2, repetition time (TR) = 2000 ms, echo time (TE) = 30 ms, flip angle (FA) = 90°. For each run, a total of 154 volumes were acquired in the main study and 184 volumes in the localizer study.

SPM8 (Wellcome Trust Centre for Neuroimaging, London, UK) was used to preprocess and analyze the imaging data. Images were adjusted for slice timing, realigned to the first scan to correct for head motion, normalized into stereotactic Montreal Neurological Institute (MNI) space with 3-mm cubic voxels, and spatially smoothed by a Gaussian filter with full-width/half-maximum parameter (FWHM) set to 8 mm. We then modeled trials of different conditions by including regressors convolved with canonical hemodynamic response function (HRF) at the onset of the presentation of outcomes. For the main study, five regressors were generated for Self Win, Self Loss, Friend Win, Friend Loss, and neutral trials. For the localizer study, three regressors were generated for Win, Loss, and neutral trials. Six motion parameters (translation: x, y, z; rotation: pitch, roll, yaw) and run-specific constant terms were also included in the model to account for effects of no interest, and whole-brain intensity was normalized using global scaling. Linear contrasts were used to identify regionally specific effects in individual participants with a fixed effect model. Random effect analyses were then conducted based on contrast images to allow population inference. For the localizer study, brain regions encoding monetary reward, specifically bilateral VS, were identified at a corrected $p < 0.05$ threshold (using a combined threshold of uncorrected $p < 0.001$ and cluster extent >21 voxels, determined by a 1000-iteration Monte-Carlo simulation; Slotnick et al., 2003) for the contrast of Win > Loss in the localizer study. This threshold was also used for other exploratory whole-brain analyses. Regions of interest (ROIs) were defined as spheres centered at the peak voxels of activations with radii of 5 mm using MarsBaR (http://marsbar.sourceforge.net). Contrast values in the main study were extracted from the ROIs by subtracting the coefficient estimates of the neutral condition from those of the experimental conditions.

Results

Behavioral results

Participants were highly accurate in their pronoun judgments during independent and interdependent self-construal priming, and accuracy did not differ across priming conditions (independent: M = 84.1%, SD = 7.2%; interdependent: M = 85.3%, SD = 5.0%; $t(14) = -0.96$, $p = 0.35$). Reaction times (RTs) were also comparable during independent and interdependent self-construal priming (independent: M = 5375 ms, SD = 84 ms; interdependent: M = 5401 ms, SD = 86 ms; $t(14) = -0.75$, $p = 0.46$).

The RTs during the card-guessing game (M = 626 ms, SD = 167 ms) did not differ across different conditions as shown by a 2 × 2 × 2 repeated-measures ANOVA involving Prime (Independent/Interdependent), Target (Self/Friend), and Outcome (Win/Loss) ($Fs < 2.90$, $ps > 0.11$). There was also no difference between the RTs of any experimental condition and those of the neutral condition ($ts < 1.52$, $ps > 0.15$).

Self-report measures

On the 8-point Likert scale of closeness between self and friend (1: no overlap; 8: fully overlap), the participants' rating scores ranged from 3 to 8 (M = 5.07, SD = 1.49).

Results from the Self-Construal scale and the Horizontal and Vertical Individualism and Collectivism scale showed that the participants were more interdependent than independent (M = 5.31, SD = 0.64 vs. 4.82, SD = 0.55, $t(14) = 3.44$, $p < 0.005$), and were more collectivistic than individualistic (M = 5.64, SD = 0.52 vs. M = 4.98, SD = 0.59, $t(13) = 3.13$, $p < 0.01$; one participant did not complete the scale). These results suggest collectivistic cultural orientation among our Chinese sample.

We conducted a 2 × 2 ANOVA to test the effect of Target (Self/Friend) and Outcome (Win/Loss) on subjective reports of feeling happy. The participants felt significantly more happy for Win than for Loss trials ($F(1,14) = 65.55$, $p < 0.001$), and there was no significant effect of Target ($F(1,14) = 3.80$, $p = 0.07$). Moreover, We found a significant interaction between Target and Outcome ($F(1,14) = 10.33$, $p < 0.01$). Whereas participants reported similar feelings of happiness in response to Self Win and Friend Win trials (M = 1.87, SD = 1.55 vs. M = 1.93, SD = 0.88, $t(14) = -0.138$, $p = 0.89$), they felt less happy in response to Self Loss trials than Friend Loss (M = −1.60, SD = 1.05 vs. M = −0.07, SD = 1.33, $t(14) = -3.36$, $p < 0.005$).

Neuroimaging results

In the localizer study, the Win vs. Loss contrast revealed a significant activation in the bilateral VS (see Fig. 2a). In the main study, this contrast also revealed significant bilateral VS activation along with activation of other regions (see Fig. 2b). In the localizer study the Loss vs. Win contrast showed significant activation in regions including the bilateral insula and the bilateral superior frontal gyrus/supplementary motor area (see Fig. 2c). Similarly, in the main study the Loss vs. Win contrast also showed activation in the bilateral insula and the supplementary motor area along with other regions (see Fig. 2d). A complete list of activated regions is given in Table 1.

To examine the effect of self-construal priming on reward-related activity, we calculated the contrast values for Win vs. neutral and Loss vs. neutral conditions in the main study in the bilateral VS defined (as defined in the localizer scan). We were particularly interested in the VS because it showed activations in the contrast of Win vs. Loss in both the localizer study and the main study, and because it has been repeatedly found to encode monetary reward (e.g. Delgado et al., 2000; O'Doherty et al., 2003). These contrast values were then subjected to a 2 × 2 × 2 repeated-measures MANOVA involving Prime (Independent/Interdependent), Target (Self/Friend), and Outcome (Win/Loss) as within-subjects variables. There was a significant main effect of Outcome (Pillai's Trace = 0.86, $F(2,13) = 39.94$, $p < 0.001$) that was confirmed by univariate tests in the left VS ($F(1,14) = 20.33$, $p < 0.001$) and the right VS ($F(1,14) = 25.41$, $p < 0.001$). Of most interest, we found a reliable three-way interaction (Pillai's Trace = 0.492, $F(2,13) = 6.29$, $p = 0.012$) that was present in both the left VS ($F(1,14) = 7.10$, $p = 0.018$) and the right VS ($F(1,14) = 12.07$, $p = 0.004$). Post-hoc analyses revealed that the Prime × Target interaction was significant for the Win trials (left VS: $F(1,14) = 17.44$, $p < 0.001$; right VS: $F(1,14) = 6.46$, $p = 0.024$), but not for the Loss trials (left VS: $F(1,14) = 0.02$, $p = 0.900$; right VS: $F(1,14) = 1.36$, $p = 0.263$). T-tests revealed that the activations for Self Win were stronger than for Friend Win after Independent self-construal priming (left VS: $M = 0.895$, SD = 0.429 vs. $M = 0.569$, SD = 0.402, $t(14) = 3.63$, $p = 0.003$; right VS: $M = 0.808$, SD = 0.488 vs. $M = 0.528$, SD = 0.460, $t(14) = 2.31$, $p = 0.037$), whereas the activations for Self Win and Friend Win were comparable after Interdependent self-construal priming (left VS: $M = 0.567$, SD = 0.994 vs. $M = 0.794$, SD = 0.952, $t(14) = -1.57$, $p = 0.139$; right VS: $M = 0.967$, SD = 0.752 vs. $M = 1.093 \pm 0.783$, $t(14) = -0.87$, $p = 0.399$; see Fig. 3).

In order to explore the effect of self-construal priming on neural activity underlying monetary loss, we defined ROIs at the bilateral insula (x/y/z = −30/14/−17 & 45/17/−11) and bilateral superior frontal gyrus/supplementary motor cortex (x/y/z = −24/14/76 & 21/2/70). We focused on these regions because whole-brain analysis revealed that they encoded monetary loss both in the localizer study and in the main study. Moreover, previous studies have repeatedly shown that the

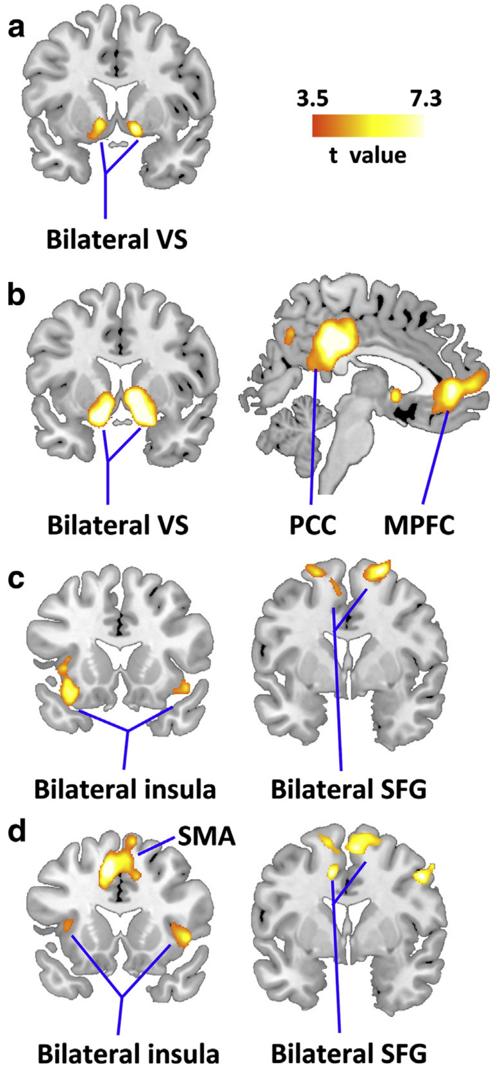

Fig. 2. Main effect of outcome. (a) Win vs. Loss in the localizer study ($y = 8$); (b) Win vs. Loss in the main study ($y = 8$ and $x = 3$); (c) Loss vs. Win in the localizer study ($y = 17$ and $y = 2$); (d) Loss vs. Win in the main study ($y = 17$ and $y = 2$). VS: ventral striatum; PCC: posterior cingulate cortex; MPFC: medial prefrontal cortex; SFG: superior frontal gyrus; SMA: supplementary motor area.

insula encodes monetary loss (e.g. Delgado et al., 2000; Paulus et al., 2003), while the supplementary motor area underlies reward-related decision-making (e.g. Gläscher et al., 2008; Haruno et al., 2004; Kouneiher et al., 2009). Although none of these regions showed a significant Prime ×Target × Outcome interaction (*F*s < 3.13, *p*s > 0.09), we did observe a marginally significant Prime × Target interaction in the right insula in the Loss condition ($F(1,14) = 3.95$, $p = 0.067$), such that the activation tended to be stronger for self trials vs. friend trials ($M = 0.55$, $SD = 0.24$ vs. $M = 0.21$, $SD = 0.25$) after Independent self-construal priming, and tended to be stronger for friend trials vs. self trials ($M = 0.37$, $SD = 0.19$ vs. $M = 0.19$, $SD = 0.23$) after Interdependent self-construal priming. However, pair-wise comparisons failed to reach statistical significance (*p*s > .15).

We also conducted correlation analyses to test whether the magnitude of the Prime × Target × Outcome interaction at the bilateral VS was associated with participants' subjective reports of happiness when winning for their friends, closeness to their friends, and trait-level measures of self-construal. However, none of these self-report measures were significantly correlated with neural activation in these regions (*r*s = −0.33 to 0.16, *p*s > 0.22).

Table 1
Brain activities to monetary win and loss in the localizer study and the main study. VS: ventral striatum; SMA: supplementary motor area.

Region	x	y	z	k	Z
Localizer study, Win vs. Loss					
Left VS	−12	5	−8	34	4.11
Right VS	12	8	−8	29	4.56
Main study, Win vs. Loss					
Left VS	−12	8	−14	152	5.09
Right VS	12	11	−11	256	5.63
Posterior cingulate cortex	3	−34	37	668	5.06
Medial prefrontal cortex	3	44	1	374	4.56
Right middle frontal gyrus	48	47	10	35	4.16
Left inferior parietal gyrus	−51	−70	52	44	3.97
Right superior frontal gyrus	24	38	49	34	3.88
Left inferior temporal gyrus	−54	−61	−11	127	3.87
Left inferior temporal cortex	−51	−49	−26	21	4.11
Right parietal cortex	33	−70	43	22	3.59
Localizer study, Loss vs. Win					
Left insula	−30	14	−17	92	4.51
Right insula	45	17	−11	256	5.63
Left superior frontal gyrus/SMA	−24	14	76	87	4.56
Right superior frontal gyrus/SMA	21	2	70	98	4.49
Left precentral gyrus	−27	−4	55	32	3.87
Right temporal pole	42	11	−44	37	4.21
Right superior temporal sulcus	48	−19	−8	38	3.93
Main study, Loss vs. Win					
Left insula	−36	14	4	29	3.48
Right insula	42	14	1	118	4.14
Bilateral superior frontal gyrus/SMA	−9	14	46	481	5.81
Left precentral gyrus	−48	−7	22	90	4.75
Right precentral gyrus	51	−1	37	35	4.13
Right supramarginal gyrus	66	−37	34	44	4.72
Right superior temporal sulcus	48	−22	−2	33	4.29

Discussion

The present study investigated whether neural responses to personal vs. vicarious rewards and losses are affected by how people construe the self in a given moment. We found that priming interdependence led to equal bilateral VS responses to rewards for the self and a friend (and in fact the trend was such that responses to friends' rewards were greater), whereas priming independence induced greater bilateral VS responses for rewards for the self than for a friend. These findings suggest that inducing a notion of self that includes close others causes rewards for the self and those others to be processed in a similar fashion, whereas inducing a notion of the self as autonomous and bounded leads to greater response to personal rewards. Although previous studies have used fMRI to explore vicarious reward, the present study provides the first evidence that neural response to vicarious rewards may be comparable to response to one's own rewards (if an interdependent self-construal is primed). Our findings suggest that self-construal may affect motivation (self vs. other-oriented) to experience rewards for a close other as strongly as they experience rewards for the self. These findings extend the literature on how self-construal may affect neural function (i.e. Chiao et al., 2009, 2010; Han et al., 2013; Lin et al., 2008; Ma et al., 2012; Ng et al., 2010; Sui and Han, 2007; Wang et al., in press; Zhu et al., 2007) by showing that vicarious reward can be modulated by temporary self-construal. Previous studies found that self-construal priming affected neural activity in cortical structures such as the mPFC (Chiao et al., 2010; Ng et al., 2010; Wang et al., 2013) and the lateral frontal cortex (Sui and Han, 2007). The current work, however, provides one of the first demonstrations that manipulating self-construal may affect the function of subcortical structures.

We should also note that although the Loss condition produced reduced activity in the VS (consistent with Delgado et al., 2000), we did not observe a Prime × Target interaction in the VS in the Loss condition. This suggests that the results we observed in the VS were not due to

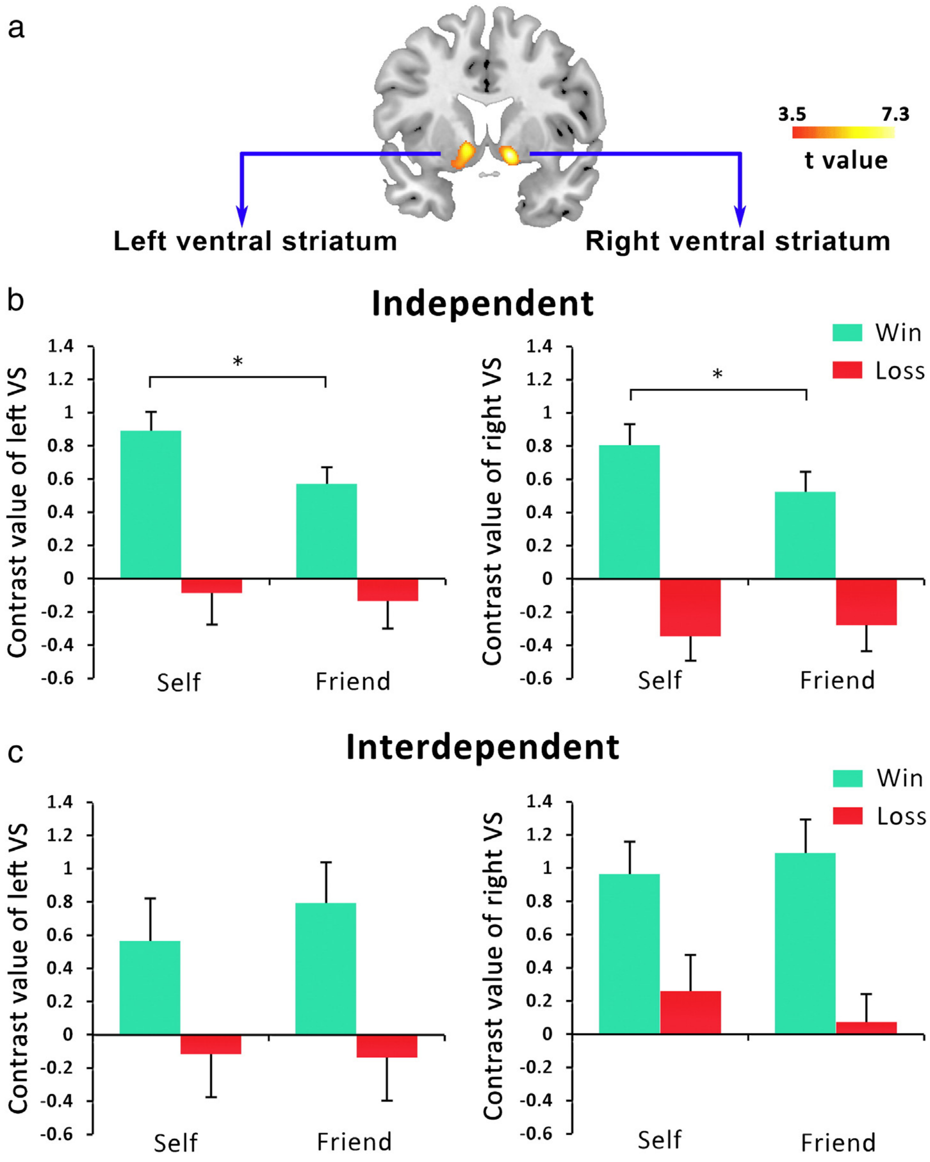

Fig. 3. Neural response in the bilateral ventral striatum. (a) Bilateral ventral striatum activation identified in localizer study (y = 8); (b) & (c) Left ventral striatum (left panel) and right ventral striatum (right panel) activation in Independent and Interdependent self-construal priming condition. (All compared to neutral condition). VS: ventral striatum.

changes in response to outcome feedback in general, but rather were specifically linked to reward feedback.

We did find a marginally significant interaction between Prime and Target on activation in the right insula during the Loss condition, such that losses for one's friend (vs. the self) produced greater activation after Interdependence priming, whereas the opposite was the case after Independence priming. Given that the insula has been implicated in empathy (for a review see Bernhardt and Singer, 2012), these results suggest that priming interdependence may have heightened empathic responses to losses for one's friend. This is broadly consistent with the previous finding that trait-level interdependence was correlated with increased error-related negativity (ERN) in response to trials where one lost points for a friend (Kitayama and Park, 2013). However, we should note that the pair-wise contrasts were not significant in the present study. This may be due to relatively limited power. We should also note that in Kitayama and Park's (2012) study, participants completed a flanker task and incorrect answers led to losses for a friend; whereas in our paradigm incorrect guesses were framed as having to do with chance rather than ability or performance (and in fact in our case feedback was rigged). Further, our study was designed such that loss trials were of smaller monetary magnitude than win trials, thus losses in general may not have been particularly painful. Future research with a larger sample (and hence greater statistical power) might explore whether modifying the relative value of loss vs. reward trials or perceived (or actual) responsibility for trial outcomes in order to test whether this might magnify the effects of self-construal priming on regions like the insula or ACC.

The present study did not measure subjective responses to individual trials (due to time constraints). As a result it was not possible to map the neural effects of the priming that were observed in the current study onto subjective reports. Future research may address this limitation by gathering real-time subjective ratings of pleasure and distress. It would also be useful in future work, if trial-by-trial ratings prove impractical, to measure subjective ratings of pleasure and distress after each set of runs (independent vs. interdependent) as this would be expected to confirm the neural results observed. In addition, it would be interesting to measure participants' physiological responses during the gambling game to assess the relationship between their autonomic and neural responses to monetary reward.

We should also note that we chose to employ a block design rather than varying the primes trial-by-trial. A trial-by-trial may be especially useful given the trend evident in the VS in the interdependent prime condition where wins for friends produced larger activations than wins for the self, as it might increase power to detect such effects. Although interspersing the trials may have increased power and decreased noise, self-construal primes are likely to have strong carry-over effects. Considering these trade-offs, we opted to employ a block design as we felt it would provide a better chance to capture the priming effects we were interested in.

Although the present study was conducted within a single culture, because of the observed effects of manipulating self-construal (a key dimension of cultural difference) the results raise the possibility that the reward system may be culturally influenced. In fact it may be that chronic cultural differences in self-construal and reward system responses to self and close others are mutually reinforcing. Our results may also have implications for research on culture and in-group/out-group phenomena. For example, the greater levels of in-group trust and favoritism that are present in interdependent societies (Yamagishi and Yamagishi, 1994; Yamagishi et al., 1998) may in part reflect greater sensitivity of the reward system to vicarious rewards for close others. Future studies might explore whether default neural responses to vicarious reward differ across cultures that differ in which type of self-construal is predominant, and whether the effects of priming are similar across different cultures. It may be illuminating to examine the effects of self-construal priming on bi-cultural participants for whom both types of self-construal may be defaults. It would also be worthwhile to test whether manipulating people's focus on their own rewards vs. rewards for close others may shift how people construe the self. That is, it would be interesting to see if having people focus on vicarious reward might lead to a more interdependent construal of the self (and whether focusing on personal rewards may lead to the self being construed in a more independent fashion). Finally, it would be interesting to test whether inducing an interdependent view of the self may also motivate people to engage in altruistic behavior toward close others, and whether individual differences in neural response to vicarious reward may be a useful predictor of future altruistic behavior.

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References

Ainslie, G., 1995. A utility-maximizing mechanism for vicarious reward: comments on Julian Simon's “Interpersonal allocation continuous with intertemporal allocation. Ration. Soc. 7, 393–403.

Aron, A., Aron, E.N., Smollan, D., 1992. Inclusion of other in the self scale and the structure of interpersonal closeness. J. Pers. Soc. Psychol. 63, 596–612.

Bandura, A., 1977. Social Learning Theory. Prentice Hall, Englewood Cliffs, NJ.

Bernhardt, B.C., Singer, T., 2012. The neural basis of empathy. Annu. Rev. Neurosci. 35, 1–23.

Bjork, J.M., Hommer, D.W., 2007. Anticipating instrumentally obtained and passively-received rewards: a factorial fMRI investigation. Behav. Brain Res. 177, 165–170.

Campbell-Meiklejohn, D., Frith, C.D., 2012. Social factors and preference change. In: Dolan, R.J., Sharot, T. (Eds.), Neuroscience of Preference and Choice: Neural and Cognitive Mechanisms. Academic Press, London, UK.

Chiao, J.Y., Harada, T., Komeda, H., Li, Z., Mano, Y., Saito, D.N., Parrish, T.B., Sadato, N., Iidaka, T., 2009. Neural basis of individualistic and collectivistic views of self. Hum. Brain Mapp. 30, 2813–2820.

Chiao, J.Y., Harada, T., Komeda, H., Li, Z., Mano, Y., Saito, D.N., Parrish, T.B., Sadato, N., Iidaka, T., 2010. Dynamic cultural influences on neural representations of the self. J. Cogn. Neurosci. 22, 1–11.

Delgado, M.R., Nystrom, L.E., Fissell, C., Noll, D.C., Fiez, J.A., 2000. Tracking the hemodynamic responses to reward and punishment in the striatum. J. Neurophysiol. 84, 3072–3077.

Fareri, D.S., Niznikiewicz, M.A., Lee, V.K., Delgado, M.R., 2012. Social network modulation of reward-related signals. J. Neurosci. 32, 9045–9052.

Gläscher, J., Hampton, A.N., O'Doherty, J.P., 2008. Determining a role for ventromedial prefrontal cortex in encoding action-based value signals during reward-related decision making. Cereb. Cortex 19, 483–495.

Han, S., Northoff, G., Vogeley, K., Wexler, B.E., Kitayama, S., Varnum, M.E.W., 2013. A cultural neuroscience approach to the biosocial nature of the human brain. Annu. Rev. Psychol. 64, 335–359.

Haruno, M., Kuroda, T., Doya, K., Toyama, K., Kimura, M., Samejima, K., Imamizu, H., Kawato, M., 2004. A neural correlate of reward-based behavioral learning in caudate nucleus: a functional magnetic resonance imaging study of a stochastic decision task. J. Neurosci. 24, 1660–1665.

Kitayama, S., Park, J., 2013. Error-related brain activity reveals self-centric motivation: culture matters. J. Exp. Psychol. Gen. http://dx.doi.org/10.1037/a0031696.

Kouneiher, F., Charron, S., Koechlin, E., 2009. Motivation and cognitive control in the human prefrontal cortex. Nat. Neurosci. 12, 939–945.

Lin, Z., Lin, Y., Han, S., 2008. Self-construal priming modulates visual activity underlying global/local perception. Biol. Psychol. 77, 93–97.

Ma, Y., Bang, D., Wang, C., Allen, M., Frith, C., Roepstorff, A., Han, S., 2012. Sociocultural patterning of neural activity during self-reflection. Soc. Cogn. Affect. Neurosci. http://dx.doi.org/10.1093/scan/nss103.

Markus, H.R., Kitayama, S., 1991. Culture and the self: implications for cognition, emotion, and motivation. Psychol. Rev. 98, 224–253.

Mobbs, D., Ronjun, Y., Meyer, M., Passamonti, L., Seymour, B., Calder, A.J., Schweizer, S., Frith, C.D., Dalgleish, T., 2009. A key reward for similarity in vicarious reward. Science 324, 900.

Ng, S.H., Han, S., Mao, L., Lai, J.C.L., 2010. Dynamic bicultural brains: a fMRI study of their flexible neural representation of self and significant others in response to culture priming. Asian J. Soc. Psychol. 13, 83–91.

O'Doherty, J.P., Dayan, P., Friston, K., Critchley, H., Dolan, R.J., 2003. Temporal difference models and reward-related learning in the human brain. Neuron 38, 329–337.

Paulus, M.P., Rogalsky, C., Simmons, A., Feinstein, J.S., Stein, M.B., 2003. Increased activation in the right insula during risk-taking decision making is related to harm avoidance and neuroticism. NeuroImage 19, 1439–1448.

Singelis, T.M., 1994. The measurement of independent and interdependent self-construals. Pers. Soc. Psychol. Bull. 20, 580–591.

Slotnick, S.D., Moo, L.R., Segal, J.B., Hart, J., 2003. Distinct prefrontal cortex activity associated with item memory and source memory for visual shapes. Cogn. Brain Res. 17, 75–82.

Sui, J., Han, S., 2007. Self-construal priming modulates neural substrates of self-awareness. Psychol. Sci. 18, 861–866.

Triandis, H.C., Gelfand, M.J., 1998. Converging measurement of horizontal and vertical individualism and collectivism. J. Pers. Soc. Psychol. 74, 118–128.

Varnum, M.E., Grossmann, I., Kitayama, S., Nisbett, R.E., 2010. The origin of cultural differences in cognition: The social orientation hypothesis. Curr. Dir. Psychol. Sci. 19, 9–13.

Wang, C., Oyserman, D., Li, H., Liu, Q., Han, S., 2013. Accessible cultural mindset modulates default mode activity: evidence for the culturally situated brain. Soc. Neurosci. 8, 203–216.

Wang, C., Ma, Y., Han, S., 2013. Self-construal priming modulates pain perception: event-related potential evidence. Cogn. Neurosci. http://dx.doi.org/10.1080/17588928.2013.797388 (in press).

Yamagishi, T., Yamagishi, M., 1994. Trust and commitment in the United States and Japan. Motiv. Emot. 18, 129–166.

Yamagishi, T., Jin, H., Miller, A.S., 1998. In-group bias and culture of collectivism. Asian J. Soc. Psychol. 1, 315–328.

Zhu, Y., Zhang, Li, Fan, J., Han, S., 2007. Neural basis of cultural influence on self representation. NeuroImage 34, 1310–1317.