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Social closeness and feedback modulate susceptibility to the framing effect

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Although we often seek social feedback (SFB) from others to help us make decisions, little is known about how SFB affects decisions under risk, particularly from a close peer. We conducted two experiments using an established framing task to probe how decision-making is modulated by SFB valence (positive, negative) and the level of closeness with feedback provider (friend, confederate). Participants faced mathematically equivalent decisions framed as either an opportunity to keep (gain frame) or lose (loss frame) part of an initial endowment. Periodically, participants were provided with positive (e.g., "Nice!") or negative (e.g., "Lame!") feedback about their choices. Such feedback was provided by either a confederate (Experiment 1) or a gender-matched close friend (Experiment 2). As expected, the framing effect was observed in both experiments. Critically, an individual's susceptibility to the framing effect was modulated by the valence of the SFB, but only when the feedback provider was a close friend. This effect was reflected in the activation patterns of ventromedial prefrontal cortex and posterior cingulate cortex, regions involved in complex decision-making. Taken together, these results highlight social closeness as an important factor in understanding the impact of SFB on neural mechanisms of decision-making.

Keywords: Framing effect; Social feedback; Decision-making; Ventromedial prefrontal cortex.

We often seek validation and advice from others when making decisions. From trivial to life changing choices—which dress to buy or whether to relocate for a job—we consistently rely upon input from others or social feedback (SFB). SFB can be expressed in many forms such as advice (Engelmann, Monica Capra, Noussair, & Berns, 2009; Engelmann, Moore, Capra, & Berns, 2012), judgment (Izuma, Saito, & Sadato, 2008), or even social ranking and comparison (Bault, Coricelli, & Rustichini, 2008, 2011). While often constructive, SFB can also be maladaptive by increasing the salience of risky options and the tendency to make irrational choices (Guyer, Choate, Pine, & Nelson, 2012; Steinberg, 2007). In fact, the mere presence of another person, a peer in particular, can affect how a reward is perceived (Fareri & Delgado, 2014; Fareri, Niznikiewicz, Lee, & Delgado, 2012) and increase adolescent risky behavior (Chein, Albert, O'Brien, Uckert, & Steinberg, 2011) and impulsivity (O'Brien, Albert, Chein, & Steinberg, 2011). Although researchers have begun to probe how SFB is processed in the human brain (e.g., Izuma et al., 2008; Somerville,

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Kelley, & Heatherton, 2010), largely focusing on the role of the ventral striatum (VS) and the ventromedial prefrontal cortex (vmPFC), little is known about how the behavioral and neural correlates of decision-making are affected when social approval or disapproval is conveyed.

We conducted two experiments investigating whether SFB from another person, either a stranger or a close friend, modulates (a) an established phenomenon of framing effect observed in a well-known paradigm (adapted from De Martino, Kumaran, Seymour, & Dolan, 2006) and (b) neural regions involved in feedback processing and decision-making (Clithero & Rangel, 2013; Delgado, 2007; Haber & Knutson, 2010; O'Doherty, Critchley, Deichmann, & Dolan, 2003). We chose the framing effect—a cognitive bias task that exposes irrational decision-making process based on how a choice is presented instead of its actual value (Tversky & Kahneman, 1974, 1981)—to further probe the well-characterized behavioral patterns elicited by this task (e.g., De Martino et al., 2006; Porcelli & Delgado, 2009). Our hypothesis was that SFB, even if unrelated to task performance, would exert an influence over decision-making in particular contexts, such as when the feedback provider was a close friend. More specifically, we hypothesized that closeness would potentiate irrational behavioral tendencies (framing effect) based on the valence of the SFB. In line with these behavioral results, we expected that the presence of a close friend would also alter neural mechanisms of decision-making (vmPFC; Clithero & Rangel, 2013) that have previously shown to be susceptible to the framing effect (De Martino et al., 2006).

In the first experiment, a confederate, unknown to the participant, conveyed SFB about task performance. In the second experiment, SFB was provided by a close friend and thus was individually tailored. In both experiments, participants faced decisions framed as either an opportunity to win or lose money (Gain and Loss frame trials, respectively). Periodically, a gender-matched confederate (Experiment 1) or close friend (Experiment 2) provided positive or negative SFB about the choices participants made. We found that the level of closeness participants have with SFB providers (confederate vs. friend) modulated the effects of SFB valence on participants' susceptibility to the framing effect. Further, we observed changes in the neural circuitry of feedback processing and value-based decision-making, namely the VS, vmPFC, and ventral posterior cingulate cortex (vPCC), as a function of the closeness between participant and feedback giver as well as SFB valence.

METHODS

Participants

Experiment 1

Thirty-three healthy right-handed individuals from Rutgers University—Newark responded to campus advertisements. One participant was excluded from final data analysis because they always chose either the safe or gamble option (resulting in empty cells for analyses). Thus, the final sample included in reported analyses consisted of 32 participants (16 female, mean age = 21.2 ± 3.7). Participants were told their compensation comprised of an hourly rate of $25 and a task performance bonus which yielded a final payoff of $65. All participants gave informed consent in accordance with policies of the institutional review boards of Rutgers University and the University of Medicine and Dentistry of New Jersey.

Experiment 2

Thirty-one healthy right-handed individuals from Rutgers University—Newark responded to campus advertisements. Four participants were excluded from final data analysis because they always chose either the safe or gamble option (resulting in empty cells for analyses). Thus, the final sample consisted of 27 participants (14 female, mean age = 20.5 ± 3.5). All participants gave informed consent and were compensated as in Experiment 1.

Paradigm and procedure

Experiment 1

The framing paradigm (Figure 1) was adapted from De Martino et al. (2006) using E-prime 2.0 (Psychology Software Tools, Sharpsburg, PA). Each trial began with an initial endowment (e.g., Receive $50) presented for 2000 ms. Participants then made a binary choice between a safe option associated with a fixed proportion of the endowment or a gamble option associated with a probability of keeping or losing the entire endowment. Participants responded with their index and middle fingers of their right hand using a MRI-compatible keypad. The experimental procedure consisted of an introduction where participants met the confederate who would be providing SFB followed by a scanner session (2 runs of 96 trials each) during which participants received SFB from the

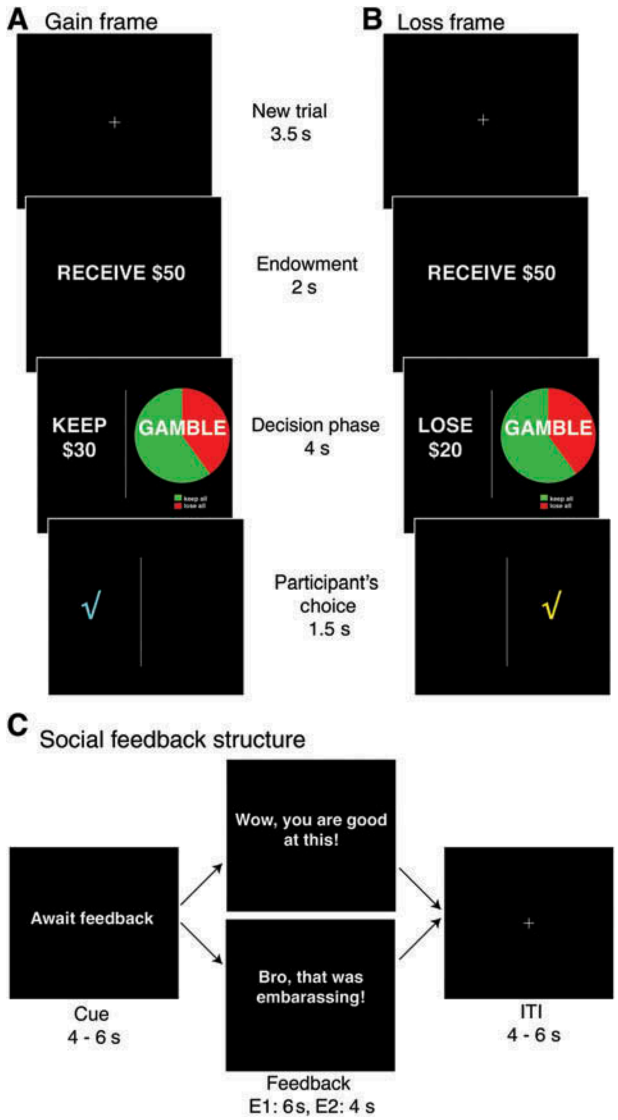

Figure 1. Experimental task. This figure illustrates the three main parts of the experimental design employed in both Experiment 1 and 2. The core task consisted of the same events per trials. Panels A and B present trial structure in gain and loss frame, respectively, showed one at a time. After a fixation cross (3.5 s) indicating the beginning of a new trial, participants were presented with a monetary endowment (e.g., Receive $50; Endowment, 2 s) before choosing between safe and gamble options presented at a decision phase (4 s). Participants were aware that they could not keep this amount and instead they were to use it to decide between two binary options: the safe option was framed such that the participant could keep (gain frame, Panel A) or lose (loss Frame, Panel B) a fixed proportion of the endowment. After each choice made, participants saw a confirmation screen indicating their choice (Participant's choice, 1.5 s). Gain frame trials were intermixed pseudorandomly with loss frame trials. No monetary outcomes were provided during the experiment. Panel C illustrates the structure according to which SFB was delivered every few trials (Experiment 1: every eight trials; Experiment 2: every two or four trials randomized). In both experiments, the delivery of SFB was preceded with a cue screen ("Await Feedback") jittered for 4–6 s. Afterwards either positive or negative SFB screen was presented for a fixed amount of time (Experiment 1: 6 s; Experiment 2: 4 s). The trial was ended with a fixation cross jittered for 4–6 s to allow for the BOLD to return to equilibrium before a new decision phase will start. The expected values of the gamble and safe options were equivalent.

confederate. Each experimental run was broken down into 32 presentations each of gain, loss, and catch trials (16 gain, 16 loss) pseudorandomly ordered.

Four different endowments were offered ($25/$50/$75/$100) in individual trials presented either in the gain or loss frame. The safe option was presented as an amount of money to be retained/lost from the endowment with certainty. For example, in gain frame trials, a safe option might involve keeping $30 of the initial $50 endowment. In contrast, on loss frame trials, the safe option might involve losing $20 of the initial $50 endowment (Figure 1). The gamble option was the same between gain and loss frame trials. Gamble options were depicted by a pie chart reflecting four distinct probabilities (20%, 40%, 60%, and 80%) of either keeping (green portion) or losing (red portion) the entire endowment. All experimental factors (endowment, probability of winning/losing, number of trials per session, SFB valence) were fully balanced within each experimental run. The expected outcomes of both options within a trial were mathematically equivalent. The only time this was not the case was when participants were presented with catch trials (as in De Martino et al., 2006). There were 32 catch trials per run that served as a manipulation check (to ensure participant's attention) and were not included in the main analysis. These trials consisted of decisions associated with a clearly dominant choice (e.g., a choice between a 95% gamble to keep all of the endowment versus a safe option to keep half of the endowment).

Participants were introduced to a gender-matched confederate from whom they would receive SFB during the scanner session. Participants were informed that the confederate would observe their choices from outside the scanner. Upon viewing the participants' responses, the confederate would periodically offer SFB about the set of choices participants had just made. Prior to the scan, participants performed practice rounds while receiving occasional SFB from the confederate seating next to them.

Participants were told that the confederate would choose between eight keyboard buttons to select specific SFB to present to the participant. Participants received these eight randomly selected SFB from the confederate (four positive and four negative) each repeated three times across the entire experiment (total 24 SFB). SFB was delivered via text projected on a screen in the MRI between "mini-blocks" (see below) of the task. Unbeknownst to participants, SFB valence and time of presentation was predetermined to ensure a controlled and balanced representation across the experiment.

Each functional run in the scanner session contained 13 mini-blocks of eight trials each. After every eight trials (or one mini-block), a SFB item was presented for 6000 ms (Figure 1C). Thus, each SFB item was presented based on the preceding mini-block, and we examined the impact of such feedback on the decisions in the following mini-block. The first mini-block was not preceded by SFB and was therefore discarded from behavioral and imaging analyses. Importantly, inclusion of intermittent SFB also increased design efficiency by introducing additional jittered fixation time, thereby reducing collinearity between key variables of interest.

Experiment 2

Procedures were similar to previously described Experiment 1 except for one important variable—SFB provider (friend)—and a few other differences. The main distinction was the inclusion of a personal, close friend of the same gender (neither a romantic partner nor a family member) as a SFB provider, rather than a confederate (see Fareri & Delgado, 2014; Fareri et al., 2012). A day before the fMRI session, participants and their friends completed a manipulation check of closeness—the Inclusion of Other in Self scale (IOS) (Aron, Aron, & Smollan, 1992) consisting of seven pairs of circles marked self and other respectively and varying in the level of overlap—and provided examples of five positive and five negative comments they would normally offer to each other when engaging in shared activities (e.g., while playing video games, basketball, or driving a car). Eight individually tailored SFB were then used during the fMRI session (e.g., "What were you thinking?") for a total of 32 SFB across two functional runs.

The framing task consisted of four functional runs (two involving SFB), each with 48 trials broken down into 24 presentations of gain and loss trials pseudorandomly ordered. Participants were informed that their friend would observe their choices from outside the scanner and provide occasional feedback on their choices. There were a few modifications from the task described in Experiment 1. First, participants were presented with two monetary endowments ($50 or $100), rather than four. Second, no catch trials were included to maximize the amount of trials for analyses. Third, SFB was provided in only two runs, as the other two runs were performed in isolation (i.e., without SFB influence). Finally, each functional run was composed of 17 mini-blocks of two or four trials each (rather than every eight trials in Experiment 1) given the removal of the catch trials. After every mini-block, a SFB item was presented for 4000 ms, and its influence on the following mini-block was assessed.

fMRI data acquisition

Experiment 1

A 3T Siemens Allegra head-only scanner and standard head coil were used for structural and functional data acquisition at the University Heights Center for Advanced Imaging. Anatomical images were acquired using a T1-weighted protocol (256 × 256 matrix, 176 1-mm sagittal slices). Functional images were acquired using a single-shot gradient echo EPI sequence (TR = 2000 ms, TE = 20 ms, FOV = 192 cm, flip angle = 80°, bandwidth = 2604 Hz/px, echo spacing = 0.29 ms). Thirty-five contiguous oblique-axial slices (3 × 3 × 3 mm voxels) parallel to the AC-PC line were obtained.

Experiment 2

A Siemens 3T Magnetom Trio whole-body scanner was used for data acquisition at Rutgers University Brain Imaging Center (RUBIC). Anatomical images were acquired using a T1-weighted protocol (256 × 256 matrix, 176 1-mm sagittal slices). Functional images were acquired using a single-shot gradient echo EPI sequence (TR = 2000 ms, TE = 30 ms, FOV = 192 cm, flip angle = 90°, bandwidth = 2232 Hz/px, echo spacing = 0.51 ms). Thirty-two contiguous oblique-axial slices (3 × 3 × 3 mm voxels) parallel to the AC-PC line were obtained. BrainVoyager QX (v2.3, Brain Innovation) was used to preprocess and analyze neuroimaging data as in Experiment 1.

fMRI data analysis

Experiments 1 and 2

Neuroimaging analyses were conducted using BrainVoyager (Brain Innovation, Maastricht, The Netherlands). Preprocessing involved motion correction (six parameter, three-dimensional) applied to the data to correct for movement and slice time correction using cubic spline interpolation to temporally align data. Further, spatial smoothing was performed using a three-dimensional Gaussian filter (4-mm FWHM), with voxel-wise linear detrending and temporal high-pass filtering. Structural and functional data were then normalized to standard Talairach stereotaxic space (Talairach & Tournoux, 1988).

Our general linear model examined brain regions exhibiting activation consistent with a framing effect. To examine this neural framing effect for both positive and negative SFB, the model included 10 primary regressors of interest. We used two regressors to model the receipt of positive and negative feedback (Experiment 1 duration: 6 s; Experiment 2 duration: 4 s). Activation corresponding to the decision phase (duration: 6 s) for trials following these feedback periods was modeled using four regressors for positive and negative feedback, yielding a total of eight decision-phase regressors. These regressors included safe and gamble choices for both loss and gain frames. In Experiment 2, we used an identical model, but also included four additional regressors of no interest to account for the decision-phase period during no feedback runs. All regressors of interest were convolved with the canonical hemodynamic response function. Activation associated with the framing effect was quantified using an interaction contrast: [(Gain_safe + Loss_gamble)—(Gain_gamble + Loss_safe)]; this contrast was computed separately for trials following positive or negative feedback. Nuisance regressors were included to account for head motion, catch trials, and missed trials. We limited our neuroimaging inferences to regions (5 mm spheres) implicated in value-based decision-making (Clithero & Rangel, 2013): vmPFC (MNI coordinates *xyz* = −2 40 −4), VS (MNI coordinates *xyz* = 10 14 −4), and vPCC (MNI coordinates *xyz* = −8 −56 20). Notably, prior work has suggested that these regions are modulated by social context (e.g., Fareri et al., 2012) and may contribute to computing social variables (e.g., Behrens, Hunt, Woolrich, & Rushworth, 2008).

Behavioral analysis

Behavioral data were analyzed using IBM SPSS Statistics 20 and MATLAB (Mathworks Inc.). Participants' choices on each trial were classified as risky (choosing the gamble option) or safe (choosing the safe option) independent of endowment and gamble probability. Choices were perfectly proportional such that an increase in the proportion of risky choices corresponded to an equivalent decrease in safe choices and vice versa. Therefore, all behavioral analyses were conducted on proportions of risky choices. A framing effect magnitude was calculated for each SFB type (positive and negative) separately. A difference score was calculated between proportions of gamble options chosen in loss as compared to gain frame trials (loss–gain). Thus, the smaller the difference, the less affected a participant was by the decision's frame (i.e., risk-taking levels would be similar in the gain and loss frames if difference scores were closer to zero).

A final consideration was exploration of the role of social closeness in decision-making. This was informed by previous work suggesting participants' sensitivity to the level of social closeness modulates participants' perception of monetary decision-making (e.g., Fareri et al., 2012). Although we did not collect IOS data in Experiment 1, we hypothesized that unacquainted dyads (cf. Experiment 1) would exhibit lower IOS scores compared to friendship dyads (cf. Experiment 2). To test this hypothesis—and validate our social closeness manipulation between

Experiment 1 and Experiment 2—we recruited 16 pairs of subjects (18 females; age range = 18:41, median = 20), all of whom indicated a lack of acquaintanceship. Of these 16 pairs, eight were gender matched; however, as matched-gender pairs did not significantly differ from unmatched-gender pairs ($t(30) = -0.71$, $p = .48$), we combined matched- and unmatched-gender pairs in our primary test. Consistent with our hypothesis, we found that unacquainted dyads (mean IOS = 1.76) exhibited significantly lower IOS scores relative to friendship dyads (mean IOS = 5.26) collected in Experiment 2 ($t(61) = -10.16$, $p < .0001$).

BEHAVIORAL RESULTS

Framing effect is observed across experiments

We examined the overall framing effect in each experiment with two separate *t*-tests comparing amount of risk taken (% gambled) when decisions were framed as loss compared to gains (Figure 2A). As expected, participants showed a susceptibility to the framing of decisions in both Experiment 1 (loss = 49.34% (±3.65%), gain = 36.88% (±.39%); $t(31) = 6.48$, $p < .001$) and Experiment 2 (loss = 51.85% (±3.46%), gain = 40.00% (±3.11%); $t(26) = 4.63$, $p < .001$), in that they chose the gamble option significantly more often for loss than gain trials. All subsequent analyses focus on investigating the changes caused by SFB valence and the level of social closeness with the provider of such input on decision-making.

Social closeness modulates the effects of SFB on irrational behavior

We next focused on the influence of SFB valence on the magnitude of the framing effect. We conducted a 2 (Experiment: 1, 2) × 2 (SFB valence: positive, negative) mixed factorial ANOVA using the magnitude of framing effect per SFB type as the dependent variable and experiment as a between-subject factor. Of particular interest was a significant interaction observed between the change in the magnitude of framing effect after SFB valence as a function of experiment ($F(1,57) = 5.2$, $p < .05$; Figure 2B). Participants' susceptibility to framing is differentially affected by the valence of the SFB, but mainly in Experiment 2 when the provider is a close friend (Figure 2B). More specifically, the influence of SFB valence on the framing effect magnitude is larger in Experiment 2 ($M = 7.61\%$; SE = 3.29%) compared to Experiment 1 ($M = 0.81\%$; SE = 1.98%), hinting that positive SFB from a friend tends to exacerbate the framing effect, while negative feedback from a friend is more likely to attenuate it. This observation supports prior findings that the mere presence of a friend can influence decision-making (Steinberg, 2007) by suggesting that the valence of SFB from a friend can influence irrational behavioral tendencies as expressed in the framing effect.

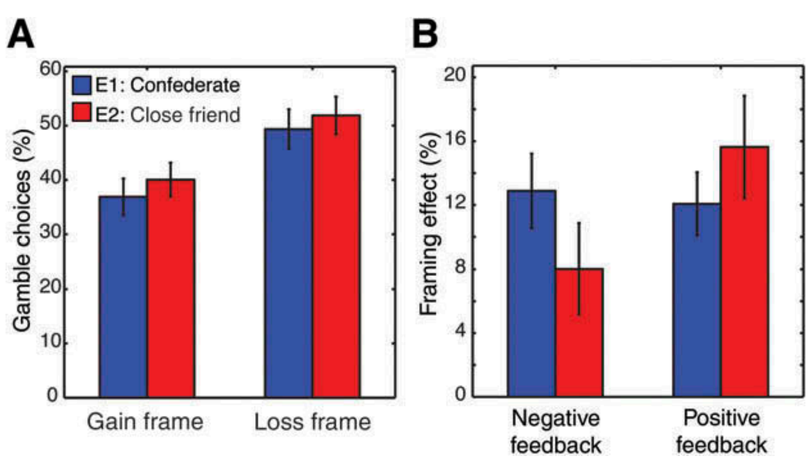

Figure 2. Social closeness modulates the effects of SFB on the magnitude of framing effect. Two panels A and B illustrate behavioral interaction between participants' choices and contextual factors. (A) The percentage of choosing gamble over safe options (*y*-axis) in either gain of loss frames (*x*-axis) in Experiment 1 (confederate, blue bar) and 2 (close friend, red bar) indicated participants' susceptibility to the way a choice was presented—that is, the framing effect. (B) Each bar represents the magnitude of the framing effect, calculated as a difference in choosing a gamble options between loss and gain frames (*y*-axis), for both positive and negative SFB (*x*-axis). Our results indicated that the effect of feedback valence was exacerbated for Experiment 2 (red) relative to Experiment 1 (blue).

One potential interpretation is that participants valued feedback from their friend more because of how helpful it is perceived. We asked participants to provide subjective ratings regarding the extent to which they viewed SFB as helpful. We observed no differences between Experiments 1 and 2 ($t(57) = 0.59$, $p = .56$), suggesting the social closeness, rather than factors such as the perceived utility of feedback, provides a better explanation for the behavioral differences across experiments.

fMRI RESULTS

Social feedback elicits responses in the ventral striatum

The human striatum has been known to respond to various types of outcomes, from monetary rewards (Delgado, Nystrom, Fissell, Noll, & Fiez, 2000) to social judgments (Izuma et al., 2008), often showing a differential response between positive and negative outcomes. We investigated if (a) positive and negative SFB would yield differential responses in the striatum in both experiments and (b) if this valence effect would be modulated by the level of closeness of the feedback provider. A 2 (feedback valence: positive, negative) by 2 (Experiment: 1, 2) mixed factorial ANOVA was performed on a VS ROI (MNI coordinates *xyz* = 10 14 −4). Consistent with previous observations, we observed a main effect of feedback valence ($F(1,57) = 16.05$, $p < .001$, see Figure 3) where VS responses were greater for positive compared to negative SFB irrespective of experiment. Two one-tailed *t*-tests showed this effect was present in both Experiment 1 ($t(31) = 3.75$, $p < .001$) and Experiment 2 ($t(26) = 1.92$, $p = .033$). No interaction between experiment and SFB valence was observed ($F(1,57) = 2.22$, $p = .15$).

Regions implicated in value-based decisions are modulated by social closeness

In meta-analyses of value-based decision-making, the vmPFC and vPCC are often identified as key neural structures (e.g., Clithero & Rangel, 2013), potentially playing a role in social and emotional aspects of valuation (e.g., Brosch & Sander, 2013). We investigated how neural signals reflecting the susceptibility to the framing effect in these two core decision-making regions were modulated by the valence of a prior SFB and its provider (confederate or friend). Specifically, we calculated the magnitude of the framing effect by computing an interaction contrast [(Gain_safe + Loss_gamble) − (Gain_gamble + Loss_safe)] for both positive and negative SFB in each experiment. This feedback-related framing effect measure was used in a mixed 2 (feedback-related framing effect: positive/negative) × experiment (1, 2) ANOVA for each ROIs separately (Figure 4). We observed a significant interaction between the feedback-related framing effect measure and experiment type in vmPFC ($F(1,57) = 5.8$, $p < .05$) and a trend for an interaction in vPCC ($F(1,57) = 3.8$, $p = .06$).

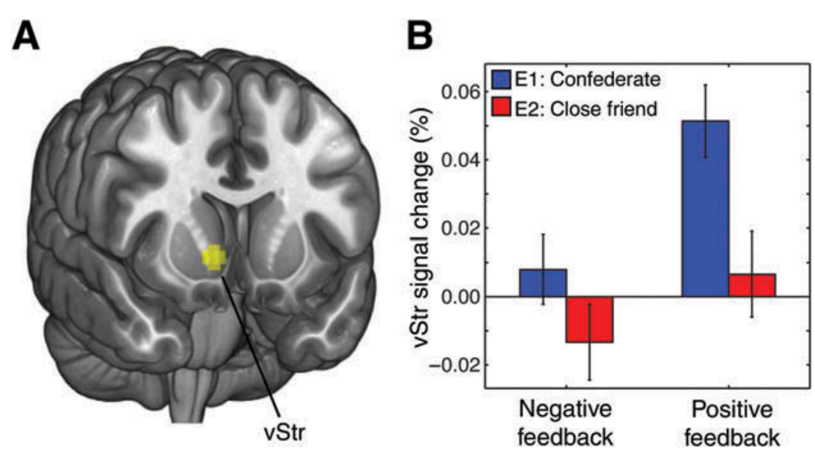

Figure 3. Ventral striatum encodes feedback valence in both experiments. (A) Ventral striatum [*xyz* = 10 14 −4] ROI was drawn based on functional meta-analysis (Clithero & Rangel, 2013). (B) Our results indicated that feedback valence modulated ventral striatum responses in both Experiment 1 (blue) and Experiment 2 (red).

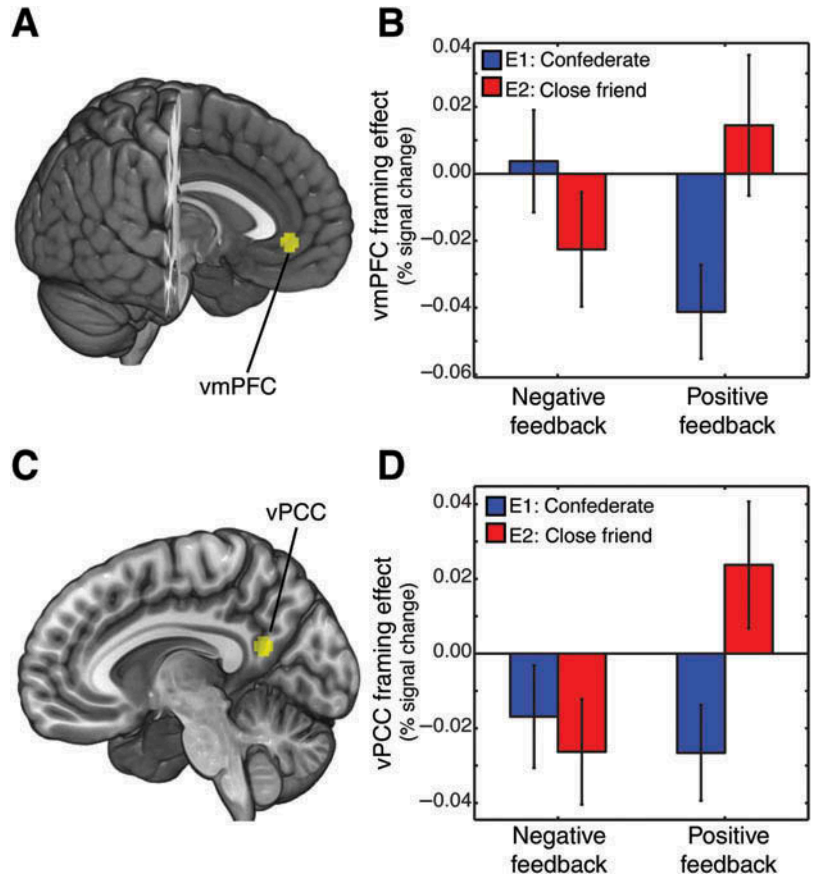

Figure 4. Social closeness modulates activation associated with the framing effect. (A) Ventromedial prefrontal cortex (vmPFC; [*xyz* = −2 40 −4]) and (C) ventral posterior cingulate cortex (vPCC; [*xyz* = −8 −56 20]). ROIs were drawn based on functional meta-analysis (Clithero & Rangel, 2013), indicating these two regions in value-based decision-making. Panels B and D depict the neural framing effect computed as an interaction contrast [(Gain_safe + Loss_gamble) − (Gain_gamble + Loss_safe)] for each condition and experiment. Our results indicated social closeness (i.e., Experiment 1 vs. Experiment 2) modulated vmPFC and vPCC responses to the framing manipulation.

DISCUSSION

The current study investigated whether feedback from a close friend influences a well-established susceptibility to the way a choice is presented—the framing effect. In two experiments, we employed a framing effect paradigm (De Martino et al., 2006) and introduced intermittent feedback from another person to test whether a prior relationship with the feedback provider (close friend or stranger) would alter established behavioral patterns elicited by the framing effect. The presence of a framing effect—being risky when a decision is framed as a loss or conservative when a decision is framed as a gain—was apparent in both experiments, regardless of who provided feedback. Critically, the magnitude of individual susceptibility to the framing effect was sensitive to the feedback valence, positive or negative, but only from a close friend. Our behavioral findings are consistent with the idea that the presence of a personal social context (i.e., SFB from a friend) can elicit adaptations in decision-making (Steinberg, 2007). We extend these findings to show this adaptation even with established behavioral tendencies, suggesting that participants potentially weigh social evaluation more heavily than the frame of a given choice if such input comes from a trusted source (i.e., close friend). A similar pattern of results was observed in structures involved in decision-making, social value, and self-referential processes (i.e., vPCC and vmPFC; e.g., Clitheros & Rangel, 2013), suggesting a potential mechanism through which SFB from a close friend can influence decisions.

The social and interactive environment in which we function often influences our decision-making process (Ariely & Norton, 2008; Kenrick et al., 2009), but the advent of investigations into the neural processes underlying social influences on decision-making is still in its infancy (e.g., Bhanji & Delgado, 2014), and only recently have investigations began to test how explicit input from others can influence neural signals associated with feedback-based adaptations on decision-making (e.g., Biele, Rieskamp, Krugel, & Heekeren, 2011). One common finding across these studies is the role of the vmPFC in processing SFB or advice from others (e.g., Biele et al., 2011; Engelmann et al., 2012; Somerville et al., 2010).

Given the involvement of the vmPFC in complex decision-making (Hare, Camerer, & Rangel, 2009, 2010; Rangel, Camerer, & Montague, 2008; Wright et al., 2012; Zaki, Schirmer, & Mitchell, 2011) particularly in value-based decision-making (Clithero & Rangel, 2013), including decisions framed as gains or losses (De Martino et al., 2006), we chose the vmPFC as a key region of exploration. Interestingly, one key difference between our study where intermittent SFB was provided and prior investigations where expert advice was given (e.g., Engelmann et al., 2012) was that there was no expectation to follow the feedback (unlike the advice). That is, participants were free to infer what valence of SFB might ensue based on their choices and either keep or shift their strategy to adjust behavior accordingly to the received feedback and the value they attached to the feedback provider. Our findings suggest that decision-related vmPFC activity is modulated by SFB. Specifically, we observed a differential pattern of activation in vmPFC based on whether the decision followed feedback of different valence and who the feedback giver was, suggesting that the vmPFC may play an important role in integrating social value of feedback as a function of social closeness to inform decisions (e.g., Gläscher, Hampton, & O'Doherty, 2009; Hampton, Bossaerts, & O'Doherty, 2006).

The other region of interest we selected, the vPCC, has been linked with both social and value-based decision-making (Clithero & Rangel, 2013). In this study, we observed that activation in ventral portions of posterior cingulate cortex were associated with the framing effect and modulated by social closeness. Although prior work has linked PCC to social cognition (Saxe, 2006), other studies have suggested that PCC may encode signals related to cognitive control (Hayden, Smith, & Platt, 2010). We speculate that these disparate accounts can be reconciled by the observation that the PCC is key cortical hub within the default-mode network (Hayden, Smith, & Platt, 2009). Indeed, recent research has indicated that PCC carries out multiple functions depending on task demands (Leech, Braga, & Sharp, 2012; Utevsky, Smith, & Huettel, 2014). One speculative idea regarding the involvement of both vmPFC and vPCC during our experiments is that an increased control over the irrational tendency to choose according to decision presentation rather than its value may be associated with increased self-referential processes (Anticevic et al., 2012; Leech, Kamourieh, Beckmann, & Sharp, 2011; Nakao, Ohira, & Northoff, 2012).

In social context, unambiguous SFB (positive or negative) carries an affective value that can be processed by similar neural mechanisms that process positive and negative affective outcomes (Delgado, 2007). This is consistent with reports suggesting that feedback from another person conveying positive information about one's reputation relies on partially overlapping neural reward circuits (Izuma et al., 2008) and that outcome processing in corticostriatal circuits is modulated by social context (Fareri et al., 2012; Mobbs et al., 2006; Rignoni et al., 2010). Interestingly, we did not observe a significant difference in striatum responses to SFB valence between Experiment 1 and 2, although an interaction approached significance; thus, it is difficult to comment on differences with respect to closeness and striatum processing of feedback in this particular experiment.

In conclusion, our results suggest that although people are susceptible to the manner in which choice is presented to us (the framing effect), this propensity can be further modulated with social relationships (social closeness). The current study has limitations based on design changes between our two experiments that were necessary to account for contextual differences (listed in the Methods). These include the between-subjects comparison, the number and frequency of experienced feedback, and the presence of catch trials (Experiment 1) or no feedback trials (Experiment 2), all of which could influence the main results presented. Importantly, however, the framing effect was observed in both experiments, and the modulation of this behavioral result was apparently mostly when the social context was driven by closeness. Future studies may benefit from including both a confederate and a close friend in the same paradigm (Fareri et al., 2012) to directly test the impact of social closeness in the same individual. Nonetheless, our results highlight the power and diversity of social influence on decision-making, potentially pointing to the mechanisms that help shape our interpersonal choices.

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