

Informing Others Is Associated With Behavioral and Neural Signatures of Value

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One of the many proclivities of our species is the drive to share information with others. What drives this unusual proclivity for propagating knowledge? Here, we test a common prediction made by recent theories in this domain: that individuals value opportunities to inform others. Two sets of studies supported this hypothesis. Behaviorally, individuals gave up money to inform others, even in “minimalistic” settings under which informing neither improved participants’ reputation nor provided material benefits to information recipients. Neurally, opportunities to inform others engaged brain regions associated with motivation and reward, including the nucleus accumbens and ventromedial prefrontal cortex. Together, these findings suggest that people place intrinsic value on sharing information with others.

Keywords: informing, altruism, reward, functional MRI

Supplemental materials: <http://dx.doi.org/10.1037/xge0000122.supp>

One of the many proclivities of our species is the drive to share what we know with others. More so than many other animals, humans exhibit a range of behaviors that serve mainly to propagate the contents of their own mind. For example, people around the world actively tutor other people, especially children, and ensure that others are aware of important cultural information, such as beliefs and traditions (Csibra & Gergely, 2009, 2011). This tendency to inform emerges early in life; before their first birthday, children begin pointing as a means of directing others’ attention (Tomasello, Carpenter, & Liszkowski, 2007). Moreover, humans are marked by physical adaptations—such as white sclera that reveal eye gaze direction (Kobayashi & Kohshima, 1997; Langton, Watt, & Bruce, 2000), facial musculature that allows for a rich set of emotional expressions (Huber, 1930), and a vocal apparatus and cognitive adaptations—that facilitate information exchange (Csibra & Gergely, 2009, 2011; Lieberman, Crelin, & Klatt, 1972). Recent technological advances simultaneously facilitate and highlight our hypercommunicative nature: each day, people publish 12 years’ worth of videos to YouTube, send 1 billion posts to Facebook, tweet 400 million messages through Twitter, and make 300,000 edits to Wikipedia.

These widespread communicative acts may stem from what researchers have identified as a species-specific motive to share information with others (Csibra & Gergely, 2011; Tomasello, 1999). That is, much in the same way that individuals are motivated to eat and drink, and value opportunities to do so, people might also value opportunities to inform others. If this is the case, we should expect individuals to treat informing others as a valued experience. Here, we use both behavioral and neuroimaging methods to test this hypothesis.

First, we used the logic of revealed preferences to measure the value individuals place on informing others (Samuelson, 1947). In two studies, participants made a series of choices that allowed us to measure how much money they were willing to forgo to inform (Deaner, Khera, & Platt, 2005; Hayden, Parikh, Deaner, & Platt, 2007). Researchers have previously used this approach to demonstrate that macaques forsake juice in exchange for visual displays of a high-status groupmate (Deaner et al., 2005) and that university students will forgo money to view visual displays of attractive members of the opposite sex (Hayden et al., 2007). Here we used this approach to test whether individuals value opportunities to inform.

Second, we assessed whether opportunities to inform activate neural structures associated with subjective value. Research on both humans and animals has demonstrated that regions of the mesolimbic dopamine system—including the nucleus accumbens (NAcc)—and ventromedial prefrontal cortex (vmPFC) respond to a broad array of primary and secondary rewards (Cohen et al., 2009; Haber & Knutson, 2010; Knutson, Adams, Fong, & Hommer, 2001; Knutson, Taylor, Kaufman, Peterson, & Glover, 2005; McClure, York, & Montague, 2004; Montague & Berns, 2002; O’Doherty, Deichmann, Critchley, & Dolan, 2002; Sabatinelli,

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The authors thank Susanna Carmona, Juan Manuel Contreras, Eshin Jolly, Jonathan Li, Joe Moran, Emma Templeton, Melissa Theiss, and Mark Thornton for their helpful advice and assistance.

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Bradley, Lang, Costa, & Versace, 2007; Schott et al., 2008; Schultz, 2002; Small, Zatorre, Dagher, Evans, & Jones-Gotman, 2001). These regions likewise respond to social rewards such as humor, social cooperation, attractive faces, sharing one's opinion, and interpersonal agreement (Fehr & Camerer, 2007; Klucharev, Hytönen, Rijpkema, Smidts, & Fernández, 2009; Mobbs, Greicius, Abdel-Azim, Menon, & Reiss, 2003; Rilling et al., 2002; Tamir & Mitchell, 2012; Zaki & Mitchell, 2011). As such, these regions provide a reliable neural marker of whether individuals assign value to stimuli. Here, we examined whether opportunities to inform likewise engage these regions.

Why might individuals imbue informing with value? In addition to examining whether individuals valued opportunities to inform, here we also evaluated several sources from which this value could arise. For example, individuals might inform as a form of self-presentation. People regularly choose to discuss their own traits, preferences, and emotions with others; and doing so activates regions associated with reward, such as NAcc (Rimé, 2009; Tamir & Mitchell, 2012). People also choose to discuss information that is not directly self-relevant as a means to signal their prosociality, trustworthiness, or investment in relationships (Camerer, 1988; Fehr & Fischbacher, 2003; Feinberg, Willer, & Schultz, 2014; Milinski, Semmann, & Krambeck, 2002); these signals may encourage others to believe that informers are useful collaborators or group members, and may generate considerable reputational value that offsets any costs of informing. As such, informing may be a means by which we satisfy our desire to display our best self to others.

Another possibility is that informing is driven by other-oriented motives. That is, people may inform because they want others to feel better. Indeed, people enjoy others' successes as a form of vicarious reward—others' good fortune is reflected in neural regions associated with personal reward, such as NAcc and vMPFC (Mobbs et al., 2009; Morelli, Sacchet, & Zaki, 2015). People not only enjoy others' well-being, they also show a strong affinity for acting to improve others' well-being (Batson, 2011). For example, people show an outsize willingness to donate material goods such as food and money (*sharing*), as well as less tangible resources such as time and effort to others (*helping*). When informing helps others—for instance helping them accomplish goals or attain resources—it likewise constitutes a form of prosociality (Feinberg, Willer, Stellar, & Keltner, 2012). As such, our tendency to propagate information may represent another form of prosocial behavior, driven by *altruistic* motives (Tomasello, 2009; Warneken & Tomasello, 2009).

Impression management and altruism likely motivate some cases of informing. For example, telling your boss about a great restaurant simultaneously demonstrates that you appreciate good food and care about her dining experiences (impression management), and may facilitate her positive dining experience (altruism). Though it is possible that people value informing entirely *because* of these factors, it is also possible that informing holds value *independent* from these external motivators. Here we arbitrate between these possibilities.

To do so, we tested whether individuals value informing even when they have little reason for doing so from the perspective of either altruism or self-presentation, by having them engage in a “minimalistic” type of informing. Participants in our studies shared only arbitrary (i.e., not personally relevant) information. They did

so anonymously, such that that their acts of informing could not reflect positively on themselves. Finally, the recipient of this information did not stand to benefit in any way from participants' informing acts, minimizing the force of altruistic motives in driving informing. Under such a “minimalistic” task design, any value associated with informing should not reflect self-serving or altruistic motives.

We further tested the extent to which informing can be explained by altruistic motives. Specifically, if it is the case that individuals inform for prosocial reasons, we should find that they value seeing the outcome of a prosocial act to the same extent as they value engaging in that prosocial act. That is, we should find evidence that individuals enjoy observing others answer questions correctly. Here we measured the value associated with observing success by measuring the neural response to seeing another person make a correct guess (rather than an incorrect one). A purely prosocial account would suggest that observing a positive outcome should be rewarding even when participants *play no role* in providing recipients with the information that would have facilitated a correct guess. However, if participants inform for reasons aside from, or in addition to prosocial motives, neural responses to observing success might diverge from neural response to informing.

In sum, the current studies used both behavioral and neuroimaging methods to test the proposition that individuals find even the most minimalistic acts of informing as rewarding. Our paradigm allowed us to test whether individuals are motivated to inform even in the absence of self-serving and altruistic motives. Finally, by measuring prosocial behaviors and vicarious reward, our paradigm further probes the role of altruistic motives in informing.

Study 1

If people value opportunities to share information with others, they should pay to do so. In this study, we tested this hypothesis by asking participants to make a series of tradeoffs between informing others and maximizing their own monetary gain.

Participants

Thirty-five (21 female; age range 18–27) native English speakers participated in this study. All participants provided consent in a manner approved by the Committee on the Use of Human Subjects at Harvard University. This sample size was determined a priori to provide power of .80 for the main effect of informing based on an estimated effect size of $d = 0.47$, derived from recent studies that also used a monetary choice task to investigate disclosure behaviors (Tamir & Mitchell, 2012).

Informing Choice Task

Participants completed the task in pairs. The task was introduced as follows:

This experiment is run in pairs. In the first part of the experiment, you will each sit in adjacent rooms—this one and the one next door—and complete an interactive task. In this task, one of you will be assigned the role of “teacher” and the other of you will be assigned the role of “learner.” In this task, the learner will attempt to guess which card from a grid of 4 is the correct card in a sequence. The correct answer

will change from trial to trial. On each trial, the teacher will be shown the correct answer. In some cases, he or she will be able to teach this correct answer to the learner.

After being separated in adjacent experiment rooms, participants were both assigned the role of teacher in the game, and both were told that their partner would be the learner, who would guess the correct card on each trial.

Each of 120 trials proceeded as follows: first, participants were shown the number (1 to 4) of the correct card for 300 ms. Participants then saw an array of 4 cards on the screen and were given 3,500 ms to press a button corresponding to this card number. Participants were then asked to choose between *informing* the learner of the correct card or *withholding* that knowledge. In both cases, participants engage in identical behaviors—first pressing a button corresponding to the correct card, and then making a decision between informing and withholding information. If participants choose to inform, they believe that the number will then be sent to the learner on that trial; if participants choose to withhold, they believe that the number will not be sent to anyone. Each option was paired with a small monetary payoff (\$0.01–\$0.04) that participants would earn for selecting that option (e.g., \$.02 to inform, \$.03 to withhold). Payoff amounts for each option varied randomly across trials, as did the option (inform vs. withhold) associated with the larger amount. The difference in value between the two options varied normally around zero. Though the values at stake in each individual choice were small, participants received the cumulative sum across all their choices at the completion of the experiment (range: \$1.10–\$3.60), in addition to a guaranteed \$8 for their participant. As such, participants could increase their total payment by approximately \$2.50 (~30%) for being entirely money oriented.

Importantly, the task and its instructions were designed to minimize potential reputational or material benefit to both study participants. First, participants were instructed that learners would not know why they received information on some trials and not on others, nor would they know that information they received came from the informer (Eckel & Grossman, 1996; Zaki & Mitchell, 2011). Thus, participants had no opportunity to signal their kindness to (i.e., their willingness to share information with) learners. Second, participants were told that neither they nor the learner could earn any extra money for guessing the correct card. In other words, information about the correct card was materially useless to learners because it would not allow them to earn or lose any additional money. As such, participants who chose to inform did so despite knowing that doing so would provide them with no reputational benefits and provide the recipient with no material benefits.

Participants were free to maximize their financial payoff by consistently choosing the option that paid the greater amount (i.e., to inform or withhold). However, to the extent that participants value sharing information, they should deviate from such economically optimal behavior and forgo money to inform. To assess this possibility, we calculated the *point of subjective equivalence* (PSE) between the two options for each participant. PSEs provide a quantitative assessment of the extent to which participants preferred informing to withholding information. For instance, an individual who does not prefer either informing or withholding, and who instead simply maximizes her own monetary payoff on

each trial, would produce a PSE of 0. By contrast, individuals who value informing—and are willing to forego money in order to do so—will produce PSEs that deviate significantly from 0. This PSE value was derived by fitting a cumulative normal distribution curve to each participant's choices (e.g., Figure 1A) and finding the monetary value at which a participant was effectively indifferent between the two options (Deaner et al., 2005). Specifically, at each value for the relative payoff between informing and withholding (e.g., informing = withholding + \$.03; informing = withholding – \$.02), we calculated the percentage of trials on which a participant opted to share information. This resulted in a total of 7 data points per subject, one at each of the relative payoffs between the two options, ranging from –\$.03 to +\$.03. Cumulative normal curves were fit to these values by implementing a Nelder-Mead simplex search algorithm in Matlab. Cumulative normal distributions are defined based on the following probability density function:

$$\frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$$

Starting values for this estimation were set at a mean of 0 and standard deviation of 1, and the search continued for 10,000 iterations, or until a solution was achieved. Final solutions of PSE were winsorized to a range of –\$.03 and +\$.03.

A cumulative normal distribution curve could not be fit to the responses of 11 participants, and thus their data were excluded from analyses on the PSE.

Results

On the whole, participants consistently preferred sharing information with others. On trials in which there was no cost to informing, when the options of informing and withholding were associated with identical monetary payoffs, participants did not choose arbitrarily between the two options (50% chance). Instead, they opted to inform their partner 71.9% of the time, significantly higher than 50% chance, $t(34) = 5.30$, $p < .001$, Cohen's $d = 0.91$. That is, even when participants would earn equivalent monetary rewards for an inform or withhold decision, they had a reliable tendency to inform. Across all trials, calculations of the PSE showed that participants gave up an average of 0.55¢ per trial to share rather than withhold information, $t(23) = 2.78$, $p = .01$, $d = 0.58$ (Figure 1B). As a result, participants forewent an average of 25.5% of their earnings to inform their study partner of the correct answer (i.e., when sharing information was worth less than withholding information). Overall, these results support the claim that people value the act of sharing information with others.

Study 2

The goals of Study 2 were threefold. First, we sought to replicate the behavioral finding from Study 1, using the same informing choice task described above. Second, we sought to extend these findings by providing convergent evidence for the value of informing using functional neuroimaging methods, and an experimental design that did not rely on explicit choice behavior. To do so, we tested whether opportunities to share information under minimalistic paradigm engage neural structures associated with valuation

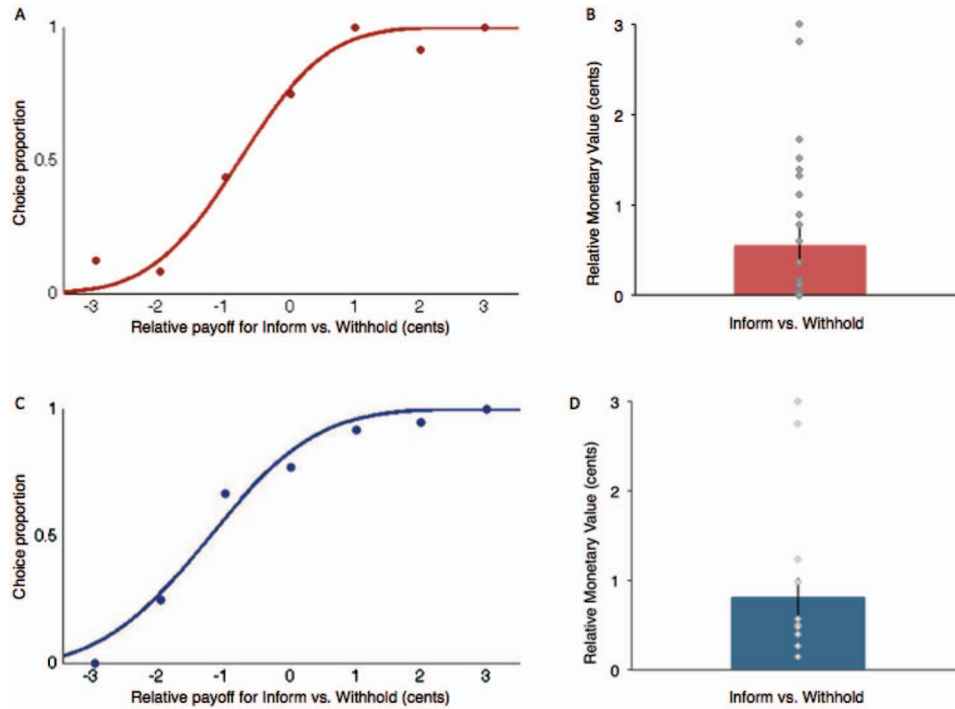


Figure 1. Monetary value of informing. Results from Study 1 (red) and Study 2 (blue) show that individuals will forgo money to inform (A, C). Representative data from 1 participant in Study 1 and Study 2. The x axis represents the difference between the monetary values associated with the two options presented on each trial. Each dot indicates the percentage of times the participant chose to share information over not sharing information (B, D). Across all participants in Study 1 and Study 2, informing was worth significantly more than not informing. Gray diamonds depict results from individual participants.

and reward. Importantly, participants in Study 2 were not given a choice between informing and withholding. Because this design instead provides an implicit measure of the value of informing, participants were not subject to factors that may have influenced participants' explicit choice behavior in Study 1. For example, participants in Study 1 may have made choices to inform because they did not want to present themselves as selfish to the experimenters, who might be viewing their choice behavior. Participants in Study 2 were not given such a choice, and so their neural responses were not subject to such self-presentation effects. In addition, participants in Study 1 might have also believed that they could finish the study earlier if the learner learned faster. Because the flow of Study 2 was fixed, and not subject to participant choices or the learner's learning rate, participants in Study 2 could no longer make this inference. To the extent that individuals implicitly value informing others, we expected such brain regions to respond more robustly when participants were given opportunities to share information with others than when they were obliged to withhold information.

Finally, we sought to further probe the relation between informing and altruistic motives. In particular, though Study 1 was designed to minimize the influence of altruistic motives on informing behaviors, participants could nonetheless inform for prosocial reasons. This is because even in the absence of monetary rewards, information recipients might have experienced guessing correctly as rewarding. If this is the case, then informers may have chosen

to forgo their own monetary gain to provide recipients with the opportunity to experience the reward of simply guessing correctly, consistent with an altruistic motive to improve recipients' well-being.

If informing in our paradigm truly represents a prosocial act, then individuals should exhibit signs of vicarious reward when observing recipients answer questions correctly (Morelli et al., 2015). Study 2 tested this proposition. In addition to the neuroimaging task measuring neural responses to informing, participants also completed a neuroimaging task designed to measure their vicarious neural responses to others' positive outcomes. In this task, participants passively observed their partner fail or succeed in guessing correctly. This task allowed us to test whether individuals exhibit the same neural reward response for observing the putative outcome of informing as they do for the act of informing.

Participants

Twenty-three (15 female) right-handed, native English speakers with no history of neurological problems participated in this study (mean age = 21.1 years; range: 18–28 years). All participants provided consent in a manner approved by the Committee on the Use of Human Subjects at Harvard University. This sample size was predetermined to provide sufficient power for the main effect of Inform > Withhold based on an estimated effect size of $d = 1.03$, derived from recent similar studies that also used neuroim-

aging to investigate the reward of disclosure behaviors (Tamir & Mitchell, 2012), as well as power of .80 to detect the same behavioral effect size observed in Study 1.

Imaging Tasks

Informing task. At the start of the experiment, an experimenter explained to the participant and a confederate that they would complete the experiment together. The task was introduced as follows: “In this task, you both will be playing a card game. One of you will be inside the scanner while you play this card game, and one of you will be outside the scanner while you play this card game. The person outside of the scanner will be the one actually choosing the cards, while the person inside the scanner will be able to watch as their study partner chooses cards. Each of you may also complete a separate set of tasks that I’ll explain to you separately.” As in Study 1, participants believed that they were playing a card game in which one participant would attempt to guess the correct card from an array of 4 cards. Participants were always assigned to the role of teacher, whereas the confederate was always assigned to be the learner, though these role titles were not actually used in Study 2 to avoid demand characteristics. As in Study 1, participants were instructed that the learner would not know that they provided any information, and that neither the participant nor the study partner could earn any extra money for using the information correctly.

Participants in Study 2 were scanned using fMRI while they played a card game similar to that used in Study 1. However, participants in Study 2 were not given a choice between informing and withholding. As such, participants did not have to act to control, or override any motive to inform, as they might have in the behavioral choice task. At the beginning of each trial, participants were shown a number from 1 to 4, which represented the correct card on that trial (500 ms). Instead, after a randomized delay of 500, 1,000, or 1,500 ms, participants were presented with a cue reading either “share” (inform trials) or “private” (withhold trials) and then were given 3,000 ms to select the correct card from an array of 4 cards. Thus, participants engaged in identical behaviors during both inform and withhold trials. On inform trials, participants’ responses were supposedly seen by their study partner; on withhold trials, participants were still asked to respond, but were told that their response was not seen by the study partner. Participants then saw the phrase “partner choosing” appear on screen for 2,000 ms, indicating that their partner was selecting a card. Participants did not see the outcome of their partners’ selection.

Participants completed a total of 50 trials of each type, divided across two functional fMRI runs of 500 s (200 TRs). Data from 1 participant who failed to respond during all withhold trials, and 1 participant who failed to respond during 85% of all trials, were excluded from all analyses. The remaining participants responded correctly on 97.2% of trials.

Outcome observation task. Participants completed a second, independent task during the scanning session. In this task, participants did not have the opportunity to share any information with their partner. Instead, they passively observed their study partner play a card game in which the partner was guessing which card out of an array of two cards was the correct card on each trial. Participants’ partner succeeded on 50% of trials and failed on the other 50%. At the beginning of each trial, the screen displayed an

array of two cards. Participants saw “partner choosing . . .” above these cards for a variable time period of either 1,000, 1,500, or 2,000 ms, during which participants were told their partner was selecting one of the two cards on screen. Participants then saw the card their partner chose (1,000 ms), denoted by text at the top of the screen (e.g., “partner chose card 1” or “partner chose card 2”); the selected card also changed color from white to blue. Finally, participants saw whether this selection was correct or incorrect, indicated by red text at the top of the screen reading either “Correct” or “Incorrect” for a randomized period of 2,000, 2,500, or 3,000 ms.

There were a total of 52 trials of each type in this task. The correct card appeared on the left and right sides of the screen equally often. Participants completed two runs of this task, each lasting 347.5 s (139 TRs). The order of the informing task and outcome observation task was counterbalanced across participants.

Monetary incentive delay task. To localize brain regions associated with computing subjective value, participants completed the monetary incentive delay (MID) task, developed by Knutson, Westdorp, Kaiser, and Hommer (2000). Each trial of the MID task began with one of two cue symbols (green circle or blue circle), displayed for 500 ms. A green cue alerted participants that they would have the chance to win a \$2 monetary reward on the trial (reward trial); a blue cue indicated that the participant could not earn any reward on the trial (neutral trial). Participants completed a total of 30 reward trials and 15 neutral trials. Cues were followed by a randomly determined delay of 2,000–2,500 ms, after which the target stimulus (white square) was briefly presented. On reward trials, participants won \$2 if they made a button press while the target was on screen, but received no reward if they responded before or after the target appeared. On neutral trials, participants were instructed to make a button press while the target was on screen, even though they could not earn any money on that trial. The target duration varied between 160 and 260 ms as a function of participants’ previous performance, such that participants would be able to respond within the window on only two thirds of trials. After the target offset, participants saw the amount of money earned on that trial (\$0 or \$2) along with the total amount earned during the task thus far. Participants completed the MID task after completing both the informing task and the outcome observation task.

Behavioral Tasks

Informing choice task. Upon completion of the scanning session, participants made a series of choices about how to trade off money for opportunities to either share or withhold information. This task was identical to that used in Study 1. PSE could not be calculated for 2 participants in Study 2, and thus their data were excluded from analyses on this measure. This provides an improvement in curve fitting from Study 1, and served to replicate those findings. The improvement in curve fitting likely resulted from participants in Study 2 providing fewer inattentive or random responses.

After the informing choice task, two behavioral tasks measured participants’ willingness to engage in two other forms of prosocial behavior: foregoing money in order to give it to their partner (*monetary sharing*) and their spending time helping their partner complete an effortful task (*time sharing*). These measures are not

discussed further here (see online supplemental materials for further description of the methods and results of these tasks).

Imaging Procedure

Functional data for all imaging tasks were acquired using a gradient-echo echo-planar pulse sequence (TR = 2,500 ms; TE = 30 ms; 3T Siemens Trio scanner; 42 axial, interleaved slices, 0 skip; 2-mm isotropic voxels). Data acquisition was optimized for signal extraction from the striatal brain regions of interest. These acquisition parameters allowed for partial brain coverage; the volumes acquired excluded the most dorsal/posterior extent of the occipital and parietal cortex. Trials were separated by a variable intertrial interval of 0 to 12.5 s. Functional images were preprocessed and analyzed using SPM8 (Wellcome Department of Cognitive Neurology, London, United Kingdom) and custom software (spm8w, Dartmouth College). Data were spatially realigned to correct for head movement, normalized to a standard anatomical space (2-mm isotropic voxels) based on the ICBM 152 brain template (Montreal Neurological Institute) and then spatially smoothed using an 8 mm FWHM Gaussian kernel. Within each run, we used custom artifact detection software (www.nitrc.org/projects/artifact_detect) to remove outlier scans, where head motion exceeded 0.5 mm or 1°, and volumes in which the overall signal exceeded 3 standard deviations from the mean global signal for that run.

Preprocessed images were analyzed using a general linear model in which the events were modeled using a canonical hemodynamic response function, its temporal derivative, and covariates of no interest (session mean and linear trend, 6 motion parameter regressors, outlier time points). Analyses for all tasks were performed individually for each participant, and contrast images were subsequently entered into a second-level analysis treating participants as a random effect. At the group level, an experiment-wise threshold of $p < .05$ corrected for multiple comparisons per Slotnick and Schacter's (2004) specifications; Monte Carlo simulations indicated use of a statistical criterion of 75 or more contiguous voxels at a voxel-wise threshold of $p < .01$.

For the informing task, the two conditions of interest (inform vs. withhold) were modeled as an event with 0 duration with an onset at the presentation of the trial type cue. Trials in which participants either chose the incorrect card or failed to choose a card were included in a single separate regressor of no interest.

For the outcome observation task, conditions of interest were modeled as events with duration lasting as long as the cue was on screen and with an onset at the presentation of the outcome cue (correct or incorrect). The model also included a regressor for the portion of every trial prior to the outcome cue, modeled as an event with a duration lasting as long as the "partner choosing" cue was on screen.

To localize brain regions associated with reward independently, we conducted two contrasts using the MID task. First, we compared responses during the anticipation period on trials on which participants could earn money and on neutral trials where they could not earn any money (Anticipatory gain > Anticipatory neutral). Second, on trials in which participants could earn money, we compared responses to feedback that participants either won, or did not win any money (Feedback gain > Feedback neutral). Both contrasts revealed activity in our a priori region-of-interest, the

bilateral NAcc ($p < .05$, corrected). In addition, the contrast of Feedback gain > Feedback neutral revealed a region of the vMPFC that responded more robustly to the receipt of monetary rewards than to the receipt of no reward. We defined spherical regions of interest with a radius of 8 mm centered on peaks of activity from these contrasts in bilateral NAcc for the anticipation period (left: -6, 7, 2; right: 10, 5, -6) and feedback period (left: -6, 7, -4; right 8, 9, -7); see Figure 2B. Finally, we anatomically defined the left and right NAcc using an independent probabilistic atlas (Hammers et al., 2003). To test how these regions of interest responded during opportunities to share information, we extracted parameter estimates (betas) from these NAcc and vMPFC regions for the Inform > Withhold contrast from the informing task.

Imaging Results

During the informing task in the scanner, participants alternately shared a piece of information with their partner or made a response that their partner did not see. We conducted two complementary analyses to determine whether brain regions associated with processing reward—specifically, the NAcc—were modulated by this task. First, we conducted a whole-brain random-effects contrast of Inform > Withhold to reveal any regions in the brain that were more activated during opportunities to inform than during trials on which participants were obliged to withhold information. Supporting the prediction that individuals value opportunities to inform, this contrast identified specifically the left NAcc and the ventromedial prefrontal cortex as more robustly active during Inform > Withhold trials (Figure 2A; Table 1). This contrast continues to reveal the same two clusters of activity at a more stringent threshold of $p < .001$, albeit at smaller cluster extents ($k = 10$ and $k = 6$, respectively).

To test whether this NAcc region overlapped with those associated with motivation and reward, we independently defined the left and right NAcc using participants' responses to the anticipation and receipt of monetary rewards during the monetary incentive delay task (Knutson et al., 2001). We interrogated these regions of interests to examine how they responded to opportunities to share information with others (through the contrast of Inform > Withhold; Figure 2B and 2D). Results of these analyses mirrored those of the whole-brain analysis, such that participants showed significantly greater activity in the left NAcc during trials in which they shared information with their partner than those on which they withheld information, but not the right NAcc (see Table 2 for full results). The vMPFC region activated by the receipt of monetary rewards also showed a marginal effect in the same direction.

In a parallel analysis, we independently defined the NAcc using anatomical definitions of the regions. We interrogated these regions of interests to examine how they responded to opportunities to inform others (through the contrast of Inform > Withhold; Figure 2C and 2D). Results of these analyses mirrored those of the above analyses, such that participants showed significantly greater activity in the left NAcc during trials in which they shared information with their partner than those on which they kept information private, but not the right NAcc (see Table 2).

In the outcome observation task, participants watched passively as their partner made either a correct or incorrect card selections.

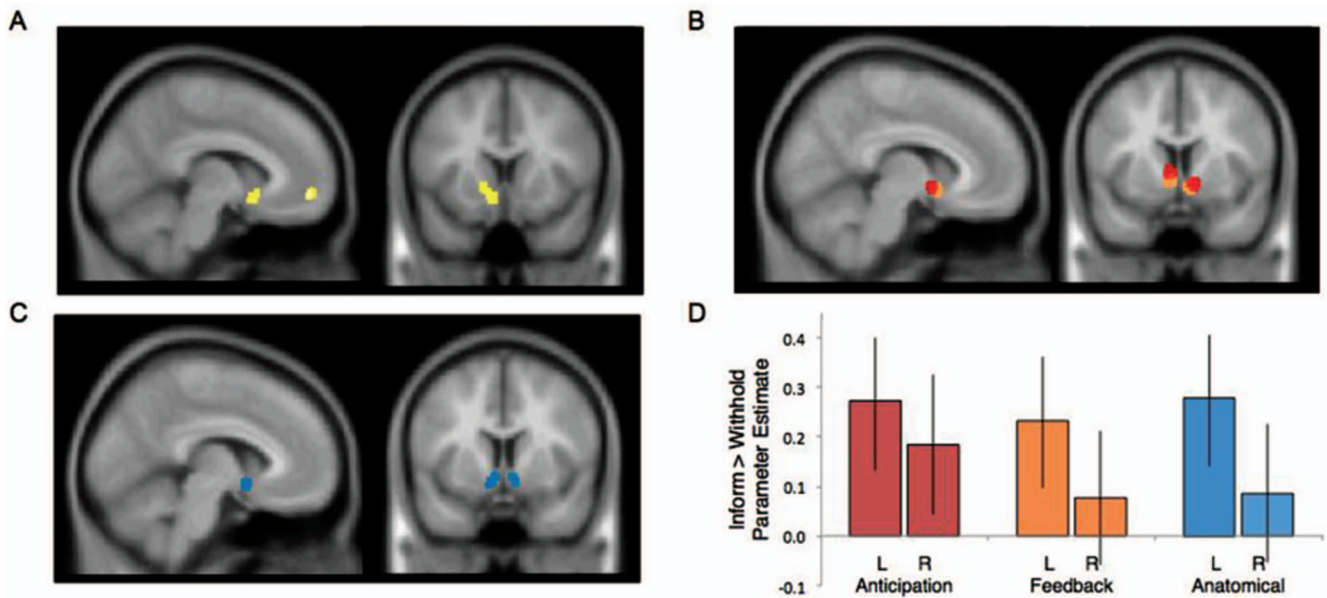


Figure 2. Neural response to informing. Whole-brain random-effects contrast of inform > withhold trials revealed modulation of left NAcc and vMPFC ($p < .05$, corrected; A). Regions of interest in the left and right NAcc were independently defined using responses during the monetary incentive delay task anticipation period (MNI coordinates: $-6, 7, 2; 10, 5, -6$; red) and feedback period (MNI coordinates: $-6, 7, -4; 8, 9, -7$; orange; B). The left and right NAcc were also defined using an anatomical definition of the NAcc (blue; C). Analysis of parameter estimates in these regions of interest confirmed that left, but not the right, NAcc showed significantly greater response during informing than withhold trials (D). Error bars depict standard error.

As for the informing task, we conducted both whole-brain and region-of-interest analyses to determine whether neural region associated with reward—specifically, the NAcc—were engaged during this task. If the value of informing derives, even in part, from the value associated with enabling another person's success—in the absence of monetary gain—then the NAcc should respond to observing successful versus unsuccessful trials. On the other hand, if the value of informing arises independent of the outcome of informing, then results from the outcome observation task should differ from those of the informing task, and not elicit NAcc activity.

Results supported this latter possibility. Whole-brain random-effects contrast of Correct > Incorrect from the outcome observation task revealed robust activity in the dorsal striatum, but not the NAcc as was the case for the informing task. To further probe this dissociation, we independently identified regions of the dorsal

and ventral stratum using both anatomical definitions of the caudate nucleus, as well the same definitions of the NAcc and vMPFC described above. We interrogated these regions of interest to see how they responded to the observation of another person's correct versus incorrect outcomes in the outcome observation task, and during inform versus withhold trials in the informing task. These

Table 2

Region-of-Interest Analyses of the Left and Right Nucleus Accumbens, and Ventromedial Prefrontal Cortex for the Inform > Withhold Contrast, and Correct > Incorrect Contrast

| Region | Informing Inform > Withhold | | Outcome observation Correct > Incorrect | |
|--|-----------------------------|----------|---|----------|
| | <i>t</i> | <i>p</i> | <i>t</i> | <i>p</i> |
| Functional regions | | | | |
| Anticipatory gain > Neutral | | | | |
| Left nucleus accumbens | 2.14 | .045 | 1.64 | .116 |
| Right nucleus accumbens | 1.30 | .209 | 1.66 | .113 |
| Feedback gain > Neutral | | | | |
| Left nucleus accumbens | 1.78 | .089 | 1.68 | .109 |
| Right nucleus accumbens | .57 | .578 | 1.12 | .278 |
| Ventromedial prefrontal cortex | 1.95 | .065 | 1.73 | .091 |
| Anatomical regions (Hammers et al., 2003) | | | | |
| Left nucleus accumbens | 2.20 | .040 | .94 | .360 |
| Right nucleus accumbens | .61 | .549 | 1.00 | .332 |
| Left caudate nucleus | 1.26 | .221 | 2.90 | .009 |
| Right caudate nucleus | .83 | .416 | 2.44 | .024 |

Table 1

Peak Voxel and Cluster Size for All Regions Obtained From the Comparison of Inform and Withhold Trials ($p < .05$, Corrected)

| Anatomic label | <i>x</i> | <i>y</i> | <i>z</i> | Volume | Max <i>t</i> |
|--------------------------------|----------|----------|----------|--------|--------------|
| Inform > Withhold | | | | | |
| Nucleus accumbens | -24 | 19 | -16 | 200 | 4.91 |
| Ventromedial prefrontal cortex | -10 | 55 | -6 | 99 | 3.73 |
| Withhold > Inform | | | | | |
| Precuneus | 26 | -55 | 20 | 313 | 5.31 |
| Superior temporal gyrus | 64 | -23 | 14 | 154 | 3.96 |
| Cerebellum | -8 | -59 | -14 | 84 | 3.58 |

analyses mirrored those of the whole-brain analyses, showing that both the left and right caudate responded significantly more robustly to correct than incorrect trials; neither NAcc nor vMPFC significantly differentiated between correct and incorrect trials (see Table 2). The inform and withhold trials in the informing task did not differentially recruit the caudate.

Behavioral Results

Results from the choice task replicated Study 1, such that participants preferred informing to withholding knowledge. When the options of informing versus withholding were associated with identical monetary payoffs, participants chose to inform their partner 80.1% of the time, significantly higher than a 50% chance, $t(20) = 7.97, p < .001, d = 1.78$. Calculations of the PSE (e.g., Figure 1C) showed that participants gave up an average of 0.81¢ per trial to inform rather than withhold, $t(18) = 3.57, p = .002, d = 0.84$ (Figure 1D). As a result, participants forewent an average of 25.5% of their potential earnings in order to inform.

In sum, participants in the informing task were given opportunities to share information with a study partner under similar behavioral and neuroimaging paradigms. Behaviorally, participants had the option to either maximize their earnings or to forgo a portion of their earnings to share information with a partner. In this task, participants gave up a significant portion of their potential earnings in order to share information with their partner. Neurally, opportunities to share information with another person recruited regions of the brain associated with motivation and reward. In contrast, observing others' experience of positive outcomes in a similar card task did not activate these regions associated with motivation and reward. These results replicate findings from Study 1 and provide converging evidence for the claim that people are intrinsically motivated to share information with others.

Discussion

People display a near-ubiquitous tendency to inform others about all manner of content: from arguing about political issues, to giving directions, to posting pictures of their breakfast on social media. Here, we employed a minimalistic design to test whether these behaviors produce behavioral and neural signatures of value. In accordance with behavioral economic indices of revealed preferences (Samuelson, 1947), people forewent material gain to share information with others. Opportunities to inform others engaged the left NAcc and vMPFC, two regions classically associated with processing subjective value. In addition, independently defined regions of interest drawn from studies of reward processing responded more to informing, as compared with not informing, others.

Further, we tested whether this value could be explained by self-presentation or altruistic motives. Although these motives may lead to informing in some cases (Feinberg et al., 2012), the current studies suggested that such motives are not sufficient to explain all informing. Here, we examined informing in a minimalistic context, in which the act of informing others was divorced from more obvious motives. Nevertheless, people shared information that was arbitrary, irrelevant to themselves, and materially useless to recipients.

These observations challenge the assertion that people provide information to others *only* for personal, social, or prosocial rea-

sons. Indeed, in everyday life, people regularly inform others in the absence of personally relevant information, reputational benefits, or personal connection to information recipients, and without observing any positive outcome to the recipient (e.g., through anonymous online reviews). Likewise, our participants appeared to value informing even in the absence of these other motives, suggesting a more basic desire to share information.

Although our data suggest that reward value provides a proximate motive for informing, they leave unclear more distal reasons as to *why* people value informing even in minimalistic contexts. One possibility is that participants' informing here represented a nonmaterial but potentially meaningful prosocial gesture. That is, participants may have believed that although learners they informed did not stand to win any money for completing the task correctly, learners might nonetheless wish to guess correctly in our card task, and might feel better following correct, versus incorrect, guesses. In fact, both behavioral and neuroimaging data suggest that people do value being correct in the absence of any material consequences (Tricomi, Delgado, McClelland, & Fiez, 2006). As such, participants in our study might have informed, and paid to do so, as a means of providing learners with a positive experience of being correct in even a consequence-free game.

We tested this possibility by measuring neural activity while participants passively observed their study partner receive feedback of exactly this type. In this task, participants saw that choices their study partner made in an independent task were either correct or incorrect. However, observing correct versus incorrect feedback did not robustly engage NAcc or vMPFC. Instead, we see shift in the locus of activity to the dorsal striatum, which may reflect the role of this region in guiding behavior by attending to behaviorally relevant action outcomes (Balleine & Dickinson, 1998; Samejima, Ueda, Doya, & Kimura, 2005). The behavior of interest here was not the participants own, suggesting a potentially novel role of this region in responding to interpersonal action outcomes. In any case, these results suggest that NAcc activity during the *act* of informing is not strongly dependent upon the positive *outcomes* to which informing contributes. That said, the tasks employed here distinguish not only between act and outcome, but also between *anticipation* of an outcome, and the outcome itself. Future work might endeavor to explore the role of anticipation, and the relation between action and anticipation, perhaps by directly comparing the reward associated with the act of informing and information receipt, within the same paradigm. Another direction for future work should be to even further minimize the experimental context in which people provide information to others, for instance, by decoupling information from any learner goals.

Second, the assertion that people appear motivated to inform others in the absence of classically posited reasons for doing so does not imply that these classic motives play *no* role in everyday informing. Indeed, real-world informing often reflects the confluence, or interaction of social and personal motives. Future work should also examine informing in more naturalistic contexts that combine reputational and prosocial features, to examine the extent to which related motives supplement or instead crowd each other out.

Third, it is possible that informing is so strongly associated with its usual positive consequences that it is difficult to untether informing from those predicted outcomes. That is, informing could

represent a case of bounded rationality (Delton, Krasnow, Cosmides, & Tooby, 2011). As such, the current experiment, though specifically designed to preclude participants from experiencing the usual consequences of informing, nevertheless, may have capitalized on participants' longstanding association of informing with positive ends (Jordan, Peysakhovich, & Rand, 2014; Rand, Greene, & Nowak, 2012). Future work should examine the development of informing behaviors, to better understand the social and personal consequences that may allow it to flourish.

Finally, it is possible that informing represents one of many opportunities people have for interacting with or connecting with each other. In this interpretation, our motivation to share information has less to do with the transfer of data from one mind to the next, and more to do with the social context of that transfer (Falk, O'Donnell, & Lieberman, 2012). There may still be reward value in matching with another person or coordinating with a group, even if it is not prosocial or reputational. Recent research shows that coexperiencing events with another person, even a minimalistic or implied social presence, similarly engages regions such as the NAcc and vMPFC (Wagner et al., 2015). By successfully limiting the personal and reputational functionality of informing, the design of this study may too have awarded participants the valued opportunity of thinking about social presence. Future research should explore the implications of this more basic social motive on our behaviors.

Conclusion

Human information sharing is both idiosyncratic and pervasive, and yet this phenomenon remains surprisingly unexplored. Prior work has suggested that informing reflects any number of sensible motives: to help others or to help one's self. Here, however, we demonstrate that opportunities to inform others—even when stripped of most meaningful consequences—nonetheless produce both behavioral and neural signatures of motivated behavior. These data suggest a novel view of informing as a deeply motivating gesture in its own right.

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Received April 2, 2015

Revision received September 23, 2015

Accepted September 25, 2015 ■