Supplementary Material

Supplementary Table 1: Demographic and neuropsychological background information.

Means (standard errors) are shown for each of the three subject groups. Age = Age of patient at time of current experiments, in years. Ed = Years of education completed. Chr = Chronicity, the time between lesion onset and the current experiments, in years. FSIQ = Full-Scale IQ from the Wechsler Adult Intelligence Scale-III. GMI = General Memory Index from the Wechsler Memory Scale-III (100 is normal). TT = Token Test (from the Multilingual Aphasia Examination), a measure of basic verbal comprehension (maximum is 44). COWA = Controlled Oral Word Association test, a measure of verbal fluency. BDI = Beck Depression Inventory, a self-report measure of depression. Social: this measure denotes the extent of post-morbid impairment in various aspects of social conduct (derived from the Iowa Rating Scales of Personality Change), rated on a three-point scale of mild, moderate, severe. Of the BDC group, 3 subjects had mild social impairments; of the VMPFC group, all but one had severe social impairments and one had mild social impairment.

Task	Age	Sex	Ed	Chr	FSIQ	GMI	TT	COWA	BDI	SOCIAL
NC	57(4)	10M/6F	15(1)	N/A	107(1)	ND	ND	40(3)	2.2 (0.6)	Normal
BDC	49(2)	8M/12F	15(1)	7(1)	101(3)	101(3)	43(1)	42(3)	5.6 (1.1)	3 mild
VMPFC	57(4)	4M/2F	13(1)	11(4)	106(8)	92(9)	44(0)	39(6)	4.0 (1.7)	5 severe

Supplementary Table 2: Precision estimates for the guilt (β) and E(α) parameters for all VMPFC patients and for one representative subject from each comparison group. We compare the original β and E(α) parameters for each individual with the median (standard deviation) parameters derived from 1000 bootstrapped samples. The parameters for each bootstrapped sample were estimated using the appropriate λ parameters from the Table 2. In many cases, a bootstrapped sample had too few unique choices and gave an unbounded parameter estimate. In those cases we replaced all such unbounded estimates with the highest bounded estimate from the remaining bootstrapped samples. For the individual where we had to use the 95%-of-the-MLE method (see Supplementary Methods) to get an estimate of E(α), we were not able to generate a precision estimate for that parameter. We were not able to generate precision estimates for the envy (α) and E(β) parameters because those estimations were more difficult and always required use of the 95%-of-the-MLE method for one parameter or the other.

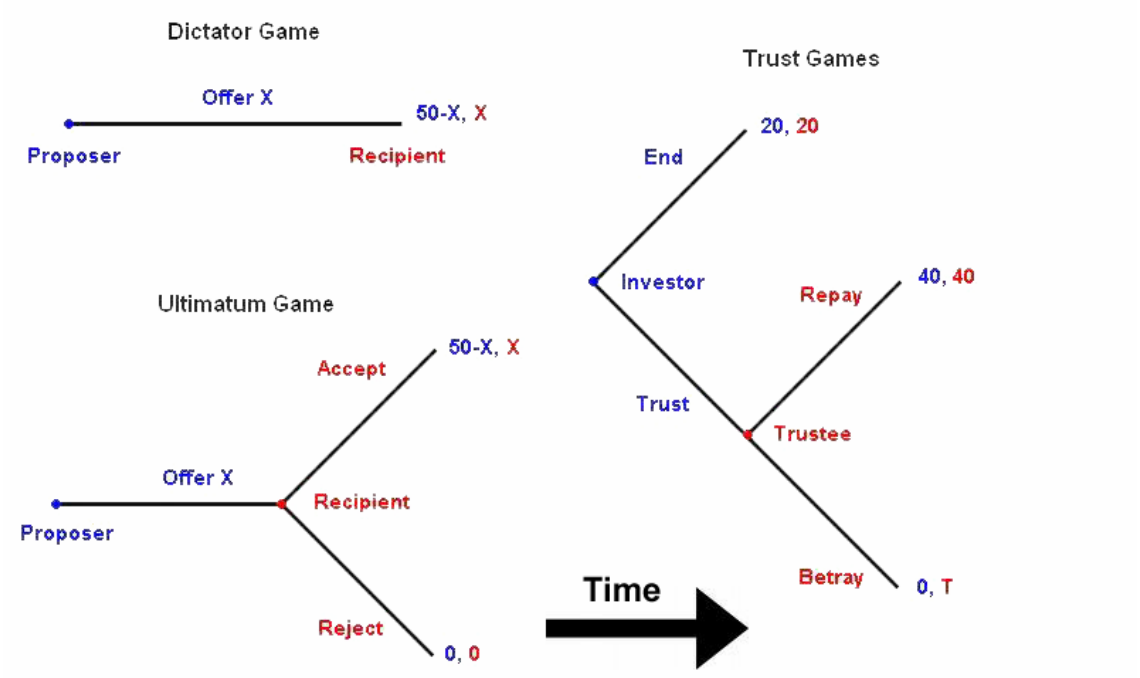
Subject	Original (β)	Bootstrapped β	Original E(α)	Bootstrapped E(α)
VMPFC	0	0 (0)	1661	NA
VMPFC	17	16 (29)	99	100 (37)
VMPFC	19	18 (29)	475	476 (173)
VMPFC	36	35 (38)	472	474 (174)
VMPFC	36	36 (24)	472	473 (175)
VMPFC	152	152 (261)	450	450 (160)
BDC	73	72 (59)	20	36 (42)
NC	202	202 (149)	479	480 (210)

Supplementary Table 3: Raw data from the VMPFC lesion patients on the dictator, ultimatum and trust games.

Subject	Dictator Offer	Ultimatum Offer	Ultimatum Demand	Trust/ Repay T=45	Trust/ Repay T=60	Trust/ Repay T=60 R=(30,30)	Trust/ Repay T=100
1	0	25	25	End, Betray	End, Betray	End, Betray	End, Betray
2	0	20	20	End, Betray	End, Repay	Trust, Betray	End, Betray
3	0	20	20	End, Repay	End, Betray	End, Betray	End, Betray
4	5	20	20	Trust, Betray	Trust, Betray	Trust, Betray	Trust, Betray
5	10	20	20	Trust, Repay	Trust, Repay	Trust, Repay	End, Betray
6	13	15	20	Trust, Betray	Trust, Betray	End, Betray	Trust, Betray

Supplementary Figure 1

Structure of the games used in our study. Extensive-form structures are shown for (a) the dictator game, (b) the ultimatum game, and (c) the trust games. Each game tree depicts the choices and payoffs for the two players, with time flowing from left to right. Every node of the tree indicates a choice, and the numbers at the right end of each branch indicate the resulting payoffs for that choice. All choices and payoffs for the first-mover are displayed in blue, while the choices and payoffs for the second mover are displayed in red. In the dictator game, subjects were asked how much money they would donate; in the ultimatum game, how much they would offer and also what they would be willing to accept if somebody else had made them an offer. In the trust game, subjects were asked whether they would Trust the other player or End the game, and also whether they would Repay or Betray the other player, contingent on him choosing Trust as the investor. Three versions of the trust game varied the temptation payoff T=45, T=60, and T=100. A fourth game used T=60 and changed the Repay payoffs to R=(30,30).



Supplementary Methods

Lesion location

Briefly, vmPFC includes the medial OFC together with dorsomedial cortex contiguous with it. Specifically it includes the gyrus rectus, medial half of the orbital gyrus, and inferior half of the medial prefrontal surface, encompassing parts of Brodmann Areas 11,12,13,25,32 and 10 as well as white matter subjacent to these. This is a definition we have used in many other studies from our laboratory as well, and it reflects the shared yet variable damage that typically produces defects in social behavior. It notably includes anterior sectors, extending to the pole, provided these are not very dorsal or lateral.

The majority of BDC lesions were in posterior regions of the brain, in occipital, parietal, and temporal lobe. Most of these were strokes, although some were neurosurgical resections. Lesion volumes encompassed a broad range; in particular, there were several subjects in the BDC group who had lesions at least as large as any in the VMPFC group. Both VMPFC and BDC groups had a large range of lesion sizes and we did not find any evidence, and have not generally in our prior studies, that lesion volume as such contributes significantly to the impairments reported.

Maximum Likelihood Estimation

The procedure finds values of α and $E(\alpha)$ (or β and $E(\beta)$) which yield an expected utility (according to formula (1) and the specific game structure) for each choice, and a probability of making each choice given those utilities and the parameter λ (according to the second equation in the methods section of the text). The MLE estimates are those values of α and $E(\alpha)$ (or β and $E(\beta)$) and λ which maximize the product of the probabilities of the choices that are actually observed. MLE estimates were done with Mathematica's NMaximize (Differential Evolution) function with ten different random seeds, using a standard log-likelihood transformation.

Truncation technique

If a subject consistently made completely altruistic or envious decisions (e.g., always offering 25 in dictator and ultimatum games, and always choosing Repay), the best parameter fit for α, β, $E(\alpha)$ or $E(\beta)$ could be infinite, which is not reasonable and limits our ability to detect differences in groups. In these cases, we found a sensible lower bound parameter giving a predicted probability equal to 95% of the probability derived from MLE. These bounds represent a compromise between the best-fitting parameter (which is larger than the bound) and the prior belief that infinite guilt and envy are not sensible. Put differently, if for example, we had used much larger values of the temptation parameter T in the trust games, we could have derived better empirical bounds on α and β, but doing so would have required more tasks and overburdened our lesion subjects.

To estimate approximate bounds on individual parameters, we used the λ value obtained from the group analysis, narrowed the parameter estimation to the individual level and determined the asymptotic MLE value for each subject with unbounded parameters. Since the MLE value is just the product of the fitted probabilities of the decisions that were made, we took its nth root, (where n is the number of decisions made by the subject), giving us a geometric mean probability. We then multiplied the geometric mean by 0.95, and used this new probability to infer a cutoff MLE value. With this value in hand, we went back to the individual's parameter estimation and found the lowest parameter combination such that the resulting MLE value was at the 95% cutoff just calculated. This procedure corrects, approximately, for the fact that by limiting the number of our games, some estimated parameter values were probably too high. Imputing the α, β, $E(\alpha)$ and/or $E(\beta)$ parameters which leads to fitted choice probabilities that are 95% as high is a way of computing a plausible lower bound which enables further analysis. That is, the bound we compute does not fit the data best, but fits only 5% worse and represents a compromise between a likely empirical value (that could be derived more precisely from a larger battery of games) and the best-fitting value, which is implausibly and imprecisely bounded in a very wide range. In many cases the envy analyses resulted in unbounded parameter estimates for both α and $E(\beta)$. In those

cases we fixed E(β) to be the highest value found in any of the other bounded estimates, and then used the 95% procedure described above to estimate α.

Binning

The MLE method does poorly when there are many possible strategies so in a few cases we rounded subjects' choices in the dictator decisions. For the dictator game, we used three possible choices: giving 0, 10 or 25 out of 50 points (1 control (4), 3 frontals (5,5,13), and 5 normals (5,20,20,20,20) were affected by this). The maximum likelihood procedure also does not work well when subjects make certain unusual choices. In a few rare cases, subjects offered or demanded more than half of the points in the dictator and ultimatum games. (This happened for n=3 subjects in dictator games, n=3 subjects in ultimatum offers, and n=4 subjects in ultimatum acceptance judgments; none were VMPFC patients.) The envy/guilt-aversion specification cannot account for such decisions because it assumes that people prefer more money to less but also have some preference for equality, so they will never sacrifice their own payoffs in a way that creates more inequality (e.g. giving more than half to someone else). In the few cases where subjects offered or demanded more than half of the points, we scaled their offers down to 25.

Supplemetary Results

Epps-Singleton

For the Trust and Repay results in Table 1, we also performed Epps-Singleton tests, which are widely used in experimental economics to test whether two samples come from the same distribution (Epps and Singleton, 1986).

For the trust decisions the Epps-Singleton p-values were:

VMPFC vs. BDC – p = 0.18

VMPFC vs. NC – p = 0.14

BDC vs. NC – p = 0.16

For the repay decisions the Epps-Singleton p-values were:

VMPFC vs. BDC – p = 0.02

VMPFC vs. NC – p = 0.05*

BDC vs. NC – p = 0.05

*Note that the Epps-Singleton test gives a warning message for this comparison, suggesting that the p-value may be inaccurate.

Supplementary References

Epps TW, Singleton K (1986) An Omnibus Test for the Two-Sample Problem Using the Empirical Characteristic Function. J Stat Comp Sim 26:177-203.