NIH Public Access
Author Manuscript
J Cogn Neurosci. Author manuscript; available in PMC 2014 August 01.

Published in final edited form as:
J Cogn Neurosci. 2013 August ; 25(8): 1372–1382. doi:10.1162/jocn_a_00398.

Abnormal causal attribution leads to advantageous economic decision-making: A neuropsychological approach

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Abstract

People tend to assume that outcomes are caused by dispositional factors, e.g., a person's constitution or personality, even when the actual cause is due to situational factors, e.g., luck or coincidence. This is known as the 'correspondence bias.' This tendency can lead normal, intelligent persons to make suboptimal decisions. Here, we used a neuropsychological approach to investigate the neural basis of the correspondence bias, by studying economic decision-making in patients with damage to the ventromedial prefrontal cortex (vmPFC). Given the role of the vmPFC in social cognition, we predicted that vmPFC is necessary for the normal correspondence bias. In our experiment, consistent with expectations, healthy (N=46) and brain-damaged (N=30) comparison participants displayed the correspondence bias when investing and invested no differently when given dispositional or situational information. By contrast, vmPFC patients (N=17) displayed a lack of correspondence bias and invested more when given dispositional than situational information. The results support the conclusion that vmPFC is critical for normal social inference and the correspondence bias, and our findings help clarify the important (and potentially disadvantageous) role of social inference in economic decision-making.

Keywords

causal attribution; decision-making; ventromedial prefrontal cortex; social inference; correspondence bias

Introduction

Humans tend to make attributions about cause and effect in all manner of situations, a behavior known as *causal attribution*. One way of categorizing causal attributions differentiates between dispositional causes, i.e., those attributable directly to the constitution of an object or agent and likely to recur across time and situations, and situational causes, i.e., those that are situation-specific, driven by capricious environmental factors and unlikely to recur. In economics, the ability to identify and invest in elements that will cause recurring monetary gain is crucial to successful investment strategies. However, some biases in human cognition, that shape fiscal decision-making, are ill-suited to maximize economic utility. One such potent bias is the tendency to surmise that outcomes are the result of causes that are attributable to an individual, i.e., caused by their dispositions, skills, and traits, rather

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than attributable to environmental causes, i.e., situational influences and constraints, luck, and other extraneous factors, and this bias can occur even when outcomes are clearly defined by situational causes. This general phenomenon is known as the correspondence bias (CB) (Gilbert and Malone, 1995; Gawronski, 2004).

Cases of gambling addiction exemplify the detrimental effects of misattributing extraneous factors. For example, a big win on a slot machine does not mean one is a "good gambler" or has "figured out" the system; instead one should attribute this windfall to chance. As this example illustrates, the CB may be a result of making an inferential leap such that situational factors are surmised to indicate dispositional traits.

Along similar lines, the CB could lead to systematic failure to make optimal decisions when making investments. In fact, poor fiscal decision-making, particularly in the realm of investment, was a major precipitating factor in the severe global economic downturn beginning around 2008. To prevent such economic disasters in the future, it is important to identify economic opportunities that will produce real, sustained gains, and avoid those associated with transient, superfluous gains. If the causes of real, sustained economic growth can be identified, then it would make sense to invest in such causes rather than in economic bubbles superfluously associated with gains.

The neural basis of the correspondence bias is not well understood. Several studies have examined the neural correlates of "self-serving attributions," whereby individuals tend to link positive events to themselves (dispositional causes) and negative events to situational causes (e.g., Miller and Ross, 1975). Among many other regions where activation changes are observed in fMRI and EEG paradigms, regions within the dorsomedial prefrontal cortex (dmPFC) stand out as particularly important sites associated with causal attribution (Blackwood et al., 2003; Harris et al., 2005; Mitchell et al., 2006; Krusemark et al., 2008; Seidel et al., 2010). Attribution of intention or 'theory of mind' has been shown to similarly involve prefrontal cortical regions, including the dmPFC and the region immediately below known as the ventromedial prefrontal cortex (vmPFC) (for a review see Abu-Akel, 2003). Likewise, moral judgement, a key component of which is attribution of responsibility, has been shown to involve the vmPFC (Koenigs et al., 2007), and so has the judgment of intention, another capacity that is closely tied to the attribution of responsibility (Young et al., 2010). To date, though, the neural basis of the specific attributional phenomenon of the correspondence bias has received little attention in the neuroscience literature. Given the lines of work summarized above and its evolutionary heritage as a centre for social evaluation, we speculated that the vmPFC may be particularly important for the CB.

The medial prefrontal cortex has been established as an important neural platform for social cognition (Damasio et al., 1990; Anderson et al., 1999; Adolphs, 2003; Amodio and Frith, 2006; Saxe, 2006; Lieberman, 2007; Shamay-Tsoory et al., 2007; Moretti et al., 2009; Van Overwalle, 2009; Forbes and Grafman, 2010); additionally, the ventromedial prefrontal cortex (vmPFC) sector is associated with representing value and future outcomes (O'Doherty et al., 2001; van den Bos et al., 2007; Moretti et al., 2009; Hare et al., 2010; Plassmann et al., 2010; Sellitto et al., 2010; Camille et al., 2011; Lin et al., 2011; Gläscher et al., 2012). We have hypothesized that the human vmPFC is likely to be involved in inferring social value due to the role of homologous regions in mammals in social evaluation of conspecifics, and we have labeled this proposition the "inferential brain hypothesis" (Koscik, 2010; Koscik and Tranel, 2012a). The notion that the prefrontal cortex and its subregions are related in some manner to human and primate evolution is prevalent in the literature (Smaers et al., 2011; Semendeferi et al., 1997, Semendeferi et al., 2002; Preuss, 2007), especially given the predominant role of the prefrontal cortex in social cognition (Adolphs, 2009). The "social brain hypothesis" is a notable example (Dunbar, 1998)—the essence being that an increased need for advanced social cognition due to living in larger social groups is the primary driving force for the evolution of the large human brain. Neural homologues to human vmPFC are critical for social evaluation and attributing value to conspecifics in most mammalian species due to their role in chemical communication via the olfactory and vomeronasal systems. In contrast, humans lack robust chemosignaling between individuals and also have strong visual specialization. Based on these evolutionary trends, we predict that the vmPFC remains important for social evaluation as in chemosensory-dependent mammals. Instead of chemosensory, perceptual identification, however, humans have shifted to a more computationally expensive form of inference. We hypothesize that the human vmPFC has been repurposed to fill this role. Humans must gather information about others from multiple sources and sensory modalities including extraneous environmental information, which creates the opportunity to utilize the correspondence bias as an attributional heuristic. For these reasons, we predicted that damage to the vmPFC would result in abnormal causal attribution (lack of a correspondence bias).

Our predictions of how the vmPFC contributes to social, causal attribution are consistent with a dual process model of causal attribution (for a review see Gilbert and Malone 1995). In this model, all information is initially labeled as dispositional. A secondary, controlled process corrects this initital dispositional attribution for situational constraints. Given that we predict that the vmPFC is involved in assigning values to others, we predict that the vmPFC is necessary for initial, heuristically driven dispositional attribution applied to all incoming information. In contrast, we predict that the vmPFC is not involved in the secondary appraisal process. Damage to the vmPFC will result in areduction in the bias toward making dispositional attributions, as the first-pass labeling of information as dispositional is damaged. In addition the secondary appraisal, making both dispositional and situational attributions, remains intact following vmPFC damage resulting in less biased dispositional and situational attributions.

In our study, participants completed an investment task, in which they could choose to invest in different investors based on either dispositional or situational information. This task allowed us to manipulate these information types in a realistic way, where dispositional information referred directly to the potential investor's attributes while situational information did not refer to the potential investor. Simultaneously, this setup allowed us to quantify the use of one type of information versus another, i.e., in the amount of money invested. We predict that normal behavior will reflect the CB, and participants without damage to the vmPFC will make an heuristically-driven inferential leap whereby situational and dispositional information will be considered to be equally diagnostic and thus investments will be similar regardless of information type. Based on the threads of evidence summarized above regarding the roles of the vmPFC in valuation, attribution, and social cognition more generally, we hypothesized that vmPFC damage would result in a failure to rely on a heuristic response guided by the CB, and would thus differentiate between dispositional information (with which vmPFC patients will invest more) and situational information (with which vmPFC patients will invest less).

Methods

Participants

We recruited 47 individuals with focal brain injuries from the Patient Registry of the Division of Behavioral Neurology and Cognitive Neuroscience in the Department of Neurology at the University of Iowa. Our target group consisted of participants with damage to the ventromedial prefrontal cortex group (vmPFC group; N = 17; 7 men, 10 women; 2 ACoA aneurysm cases, 4 ischemic stroke cases, 2 resections, 9 benign tumor removals). We also recruited a brain damaged comparison group whose brain damage did not include vmPFC (BDC group; N = 30; 17 men and 13 women; 24 ischemic stroke cases, 1 resection, 5 benign tumor removals) (see Figure 1). Participants whose lesions encompassed mainly either the amygdala or insular cortex were excluded from our sample, given that those structures are known to be important for social cognition and emotion. In addition, we recruited 45 neurologically normal participants (22 men, 23 women) from the Iowa City area as a normal comparison group (NC group) (see Table 1). All participants with focal brain damage were recruited from the Patient Registry of the Division of Behavioral Neurology and Cognitive Neuroscience in the Department of Neurology at the University of Iowa. All participants were free of dementia, psychiatric disorder, substance abuse, and significant intellectual impairments. Normal comparison participants were recruited from the Iowa City area through advertisement, and were compensated for their participation. All participants provided informed consent prior to participation in accordance with the Institutional Review Board of the University of Iowa.

Participants were predominantly right-handed and all were of western European descent. There were no differences between groups in age ($F(2,91) = 0.874$, $p = 0.421$); there was a small but statistically significant difference in years of education ($F(2,91) = 6.411$, $p = 0.003$). Post hoc tests revealed that the vmPFC group differed significantly from the NC group in education ($p = 0.003$); all other comparisons were non-significant (see Table 1).

Brain damaged groups did not differ in lesion chronicity (i.e., time since lesion onset) ($t(45) = -0.871$, $p = 0.388$). All neuroanatomical, neuropsychological, and experimental data were collected approximately contemporaneously—specifically, during the chronic epoch of recovery (more than 3 months post onset), where neuroanatomical and neuropsychological profiles are stable. Brain-damaged participants had, for the most part, intact psychometric intelligence, memory, executive functions, and verbal abilities (see Table 1). Moreover, there were no significant differences between the vmPFC and BDC groups for any neuropsychological variables (all $ps > 0.327$), except for the score on the Beck Depression Inventory (BDI) where the vmPFC group ($M = 3.93$, $SD = 4.95$) had lower BDI scores than the BDC group ($M = 8.14$, $SD = 5.76$) ($t(40) = -2.335$, $p = 0.025$) (see Table 1). However, BDI scores of 13 or lower are classified as 'minimal depression,' so neither of the groups had average depression in the clinically elevated range.

Procedure

Participants completed an investment decision-making task, in which they freely chose how much to invest with different investors based on a brief description of the investors' prior investing success. These descriptions contained either dispositional information, e.g., "Investors made 10% last year due to his hard-working nature," or situational information, e.g., "Investors made 10% last year due to economic growth in China" (see Table 2). On each trial, participants were sequentially presented with two potential investors with whom they could invest some or all of their money with either or both investors however they saw fit. Participants were required to invest a minimum of $10 on each round.

At the beginning of each trial, participants were instructed to complete an unrelated task to earn money to invest. We had two reasons for requiring participants to work for their investment money: 1) it allowed us to introduce a lag between trials (between 5 and 10 minutes) to assist in separating decisions in time to potential reduce the impact of prior decisions and 2) investing money that was earned rather than given may increase the incentive to invest this money wisely. Participants completed two versions of each of these tasks in the same order and every four trials received money for free, i.e., without completing a task, thus resulting in 8 trials in total. These unrelated tasks consisted of a hidden covariation detection paradigm (where perceptual properties of stimuli varied systematically with on-screen information, and detection of this hidden covariation was probed), an inhibition of return paradigm (an attentional cueing task where participants respond to cued and uncued targets), and an arithmetic task (consisting of simple mathematic problems). The results of these unrelated tasks are as of yet unpublished. Money that participants were to invest was not contingent on performance of these unrelated tasks, rather participants received $100 in facsimile money to invest for each trial.

After earning money on the unrelated tasks, participants read descriptions of two people with whom to potentially invest. Descriptions included a picture of an individual and varied in terms of either containing dispositional or situational information counterbalanced for order of presentation (see Table 2 for descriptions). Pictures consisted of emotionally neutral, all male, European, middle-aged, frontal view, computer generated faces (using FaceGen Modeller, Singular Inversions Inc., 2009). Dispositional information included a reference to something internal to the individual with an explicit, direct referent to the investor (i.e., his), whereas situational information referred to circumstances that were external to the individual and beyond their control, without an explicit, direct referent to the investor. For example, dispositional information, “John Smith: Investors made 10% last year due to his hard-working nature,” versus situational information, “Bill Johnson: Investors made 10% last year due to economic growth in China.” The percentage of gain was exactly the same for both descriptions on a given trial, but varied between trials in 5% increments from 5% to 20%, in a pseudo-randomized order, such that all descriptions were framed to be positive, i.e., potential investees were described to have made money for varying reasons. After reading the descriptions, participants allocated their investment however they wanted by clicking on-screen buttons to add or subtract money from each potential investee, and the remainder was placed in a “bank” for them. A new trial then began with another unrelated task to earn money and begin the process again.

Following all of the investment decisions, participants were asked to predict how well each of their investments would do. Finally, participants were given feedback on how well their investments fared (all were associated with the same gain as in the descriptions that were given) and were asked to decide how much they would like to reinvest if given the opportunity. Three trials were catch trials that contained either only dispositional (2 trial) or only situational (1 trial) descriptions, allowing us to examine these two factors in isolation as well. Given that the limited time volunteered by these participants for research and the high demand for them, time constraints only permitted a limited number of trials.

Our main dependent variable from this task is the difference between the amounts invested when given dispositional information and the amounts invested when given situational information. If participants are susceptible to the correspondence bias, then we would expect the difference between the amounts they invested when given dispositional information and the amounts they invested when given situational information should be reduced. In other words, if situational information is considered to be of equal diagnostic value as dispositional information then participants will invest similar amounts regardless of information type. A more ‘rational’ pattern would be to invest more money when given dispositional information, i.e., to capitalize on someone’s skill, and avoid situational information, i.e., to reduce the influence of less predictable loss. We predicted that both BDC and NC groups would display the correspondence bias and show greater deviation from ‘purely rational’ investments, reduced difference between dispositional and situational investments. In contrast we predicted that vmPFC damage would result in abnormal social evaluation, demonstrated by a lack of the correspondence bias, and would thus follow the ‘more rational’ pattern of investing proportionally more with dispositional information and less with situational information.

Lesion Analysis

Neuroanatomical analysis was based on MR or CT images obtained in the chronic epoch of recovery. Each brain lesion was reconstructed in three dimensions using Brainvox (Damasio and Frank, 1992; Frank et al., 1997) and manually warped to a normal template brain using the MAP-3 technique (Damasio et al., 2004). Following manual transfer to the normal template space, the template brain was warped to the MNI152 standard 1mm T1-weighted atlas (Evans et al., 1991; Collins et al., 1994; Mazziotta et al., 2001) to provide a more direct comparison to a large portion of the literature that also uses this standard space. This warping was accomplished using BRAINSDemonWarp (Johnson and Zhao, 2009), which is a high dimension image registration algorithm that generates displacement vectors for each voxel to define the transform from the moving to fixed image (Thirion, 1998). This transform, from the lesion template to the MNI152 template, was then applied to each of the lesion maps. Lesion maps were then processed with Matlab (r2007b, The Mathworks), in order to create overlap maps of pertinent participants.

Naturally occurring brain lesions do not respect functional or anatomical boundaries, thus an all-or-none approach to classifying lesions is inappropriate. Likewise, anatomical parcellation schemes give a false impression of distinct, abrupt boundaries between regions, thus, lesions that have their focus in an adjacent, non-target region may spill-over in the periphery of the region of interest, but not affect the core of this region to a significant extent. Our solution to this classification problem was two-fold. First our recruitment procedures targeted participants with known damage to the vmPFC, our region of interest. All but two participants with vmPFC damage had bilateral vmPFC lesions (one patient had unilateral left vmPFC damage, and one had unilateral right vmPFC damage). Second, to exclude participants with damage limited to the periphery of our region of interest, we set a lower limit on the proportion of damaged voxels for inclusion at 5% of the volume of the vmPFC in either hemisphere. In our sample, of the lesions confined entirely to the vmPFC, the smallest proportion of the vmPFC that is covered is approximately 5.5% (a unilateral lesion confined entirely within left vmPFC); six subjects with foci of damage in regions adjacent to the vmPFC have some spill-over (with an average 1.1% coverage of bilateral vmPFC, maximum 2.0%). These data were then visualized using MRIcroN (Rorden, 2007, 2008) (see Figure 1). Brain damage in the vmPFC group affected significantly larger volumes of neural tissue (M = 4.8, SD = 3.4, expressed as a percentage of all voxels representing neural tissue) compared to the BDC group (M = 2.6, SD = 3.2) ($U = 131.0$, $p = 0.006$).

Statistical Analyses

For our primary analysis, we compared vmPFC, BDC, and NC groups on the difference between the amounts of money invested following dispositional descriptions and situational descriptions using a one-way analysis of variance (ANOVA) procedure. We planned to use Tukey’s post hoc test to locate significant between-group differences. To account for between-subjects differences in absolute investment behaviour (i.e., since some participants will tend to invest more than others in general), the amount of money invested with either information type will be taken as a proportion of the total amount invested on that trial.

Given that we observed group differences in education (i.e., vmPFC had fewer years of education than NCs as reported above), we planned to examine whether or not this affected our results. First, we examined the correlation between education and our dependent variable. Second, we used an analysis of covariance (ANCOVA) with education as a covariate to examine the effect of education or our results. Similarly, since we observed group differences in overall lesion size, we examined potential correlation and an ANCOVA to examine whether or not overall lesion size affected our results.

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Secondarily, we planned to examine whether or not any group differences were due to differential investments to specific changes to either dispositional or situational investments. For example, if the vmPFC group displayed an increased difference between dispositional and situational investments, this could be due to an increase in the amount dispositional investments alone, a decrease in situational investments alone, or a combination of both. We examined this in two ways: 1) we compared the amounts invested for dispositional and situational information (i.e., the same variables used to calculate the difference score) and 2) we examined the investments made on catch trials where there was no choice between dispositional versus situational information types. Note that analysis of catch trials will be in terms of absolute investment amount, since calculation of the amount invested by information type as a proportion of the amount invested on that trial, as above, will always result in a value of 1. Since the calculation of values on catch trials, does not involve a proportional measure, and may partially reflect inter-individual differences in investment thresholds we will use an ANCOVA procedure with the average absolute amount invested as a covariate. To further examine whether or not groups differed in general investment thresholds, we ran another follow-up analysis comparing absolute investment values including all trial types. This will allow us to determine whether any of our groups are more fiscally conservative or more or less likely to invest their money.

Next, we analyzed whether or not the vmPFC, BDC, and NC groups differed in their predictions of how they felt their investments would yield and their willingness to reinvest money given the outcome of their previous investment. As in our primary analysis we submitted the difference between dispositional and situational investments to one-way ANOVA, using Tukey's post hoc tests to pinpoint any potential group differences.

Finally, we performed an exploratory analysis to explore the possibility that there is functional specificity with regards to our results within vmPFC subregions. Given that this exploratory analysis will rely on a relatively small sample to look for these within-group relationships, we limited this analysis to subregions within the prefrontal cortex where 5 or more participants in the vmPFC group had any damage to that region. We examined correlations between the extent of damage to a vmPFC subregion and the difference between the amount invested by information type. Given the exploratory nature of this analysis we will report significant findings at a liberal, $\alpha < 0.1$, threshold; moreover we will only report vmPFC subregions with a significant relationship.

Results

Our primary analysis of the difference between dispositional and situational investments revealed significant differences between groups ($F(2,91) = 8.461$, $p < 0.0005$, $\eta^2 = 0.160$). Post hoc tests revealed that the vmPFC group had a significantly greater difference in investments by information type compared to the BDC group ($p < 0.0005$, 95% CI [0.107, 0.405]) and the NC group ($p = 0.006$, 95% CI [0.045, 0.326]) (see Figure 2). As predicted, participants with vmPFC damage invested more money when given dispositional information than when given situational information. In contrast, comparison groups did not vary investments by information type, displaying the correspondence bias.

A closer examination of these data demonstrates that the difference observed between groups in our main analysis was due to the behavior of the vmPFC group, which had both increased investment for dispositional information ($F(2,91) = 9.055$, $p < 0.0005$, $\eta^2 = 0.169$) and decreased investment for situational information ($F(2,91) = 6.473$, $p = 0.002$, $\eta^2 = 0.123$) (see Figure 3). However when we looked at catch trials only, i.e., when there was no choice between the different information types, there were no differences between groups for dispositional-only ($F(2,88) = 0.656$, $p = 0.522$) or situational-only ($F(2,88) = 0.572$, p =

0.567) information (see Figure 4). Group differences were present only under circumstances where a choice between dispositional and situational information was necessary. Thus, we do not observe a systematic avoidance of or attraction to either information type in any of our groups. Moreover, this suggests that participants do not necessarily differ in their understanding of the information types per se, rather they differ in their usage of this information when presented with differing options. It is possible that the correspondence bias does not become activated unless a choice between dispositional and situational information types is required. Future research could benefit from being designed to resolve this possibility.

In addition, the absolute amount invested with either information type (as opposed to the proportion of the total amount invested as presented above) did not differ between groups [dispositional: ($F(2,89) = 0.371$, $p = 0.691$), vmPFC mean = 24.75 SD = 9.93, BDC mean = 25.67 SD = 12.60, NC mean = 23.36 SD = 11.39; situational: ($F(2,89) = 2.129$, $p = 0.125$), vmPFC mean = 20.50 SD = 8.66, BDC mean = 28.27 SD = 14.21, NC mean = 24.49 SD = 12.71]. Given the relatively large between subjects variability in absolute investment as demonstrated by the relatively large standard deviations our comparison of dispositional and situational investments as a proportion of the total amount invested helped control for this variability in our main analysis. Importantly, the amount not invested (i.e., banked by the participant) did not differ between groups (vmPFC mean = 77.11 SD = 8.97, BDC mean = 73 SD = 12.84, NC mean = 76 SD = 11.61) ($F(2,89) = 0.820$, $p = 0.444$). This suggests that the groups did not differ in terms of fiscal conservatism and likelihood to invest their money, despite between-participants variability in this regard. In other words, fiscal conservatism was not specific to one group.

Education did not account for performance on the task. Years of education was not correlated with the difference in the amount invested between dispositional and situational information types ($r = -0.065$, $p = 0.535$). Moreover, an ANCOVA analysis revealed no significant effect of education ($F(1,88) = 0.012$, $p = 0.914$), and the group effect remained ($F(2,88) = 8.153$, $p = 0.001$).

Overall, lesion size was correlated with the difference in the amount invested by information type ($r = 0.367$, $p = 0.011$). However, including lesion size as a covariate in our ANCOVA, did not alter the group (lesion location, vmPFC vs BDC) effect ($F(1,43) = 8.033$, $p = 0.007$). There was a weak trend toward lesion size having an effect ($F(1,43) = 3.152$, $p = 0.083$), but there was no group by lesion size interaction ($F(1,43) = 1.190$, $p = 0.281$). Overall, lesion size is less important than lesion location, which is consistent with modern conceptualizations of functional modularity of the brain.

Additionally, we observed no difference between groups in their predictions of how well their investments would do, ($F(2,91) = 0.380$, $p = 0.685$), nor did we observe any differences in in reinvestment following feedback ($F(2,91) = 0.267$, $p = 0.767$).

Finally, our exploratory analysis revealed several regions that may be of particular importance within the vmPFC (see Figure 5). In the left hemisphere, the subgenual cingulate cortex ($r = 0.450$, $p = 0.069$) and straight gyrus ($r = 0.472$, $p = 0.056$) are related to the larger differences in the amount of money invested by information type. No other regions in either hemisphere were related to larger differences (all p's> 0.1). However, in the right hemisphere, the lateral orbitofrontal cortex displayed a weak negative relationship with the difference in the amount of money invested by information type ($r = -0.413$, $p = 0.099$).

Discussion

The findings support our prediction that damage to the vmPFC would result in a deficit in normal causal attribution, and that this would translate into abnormal (advantageous, under the circumstances rigged up in our study) investment decisions. Participants with vmPFC damage were less likely to exhibit the correspondence bias, investing proportionally more money when given dispositional information than when given situational information. In contrast both brain damaged and neurologically normal comparison participants exhibited the correspondence bias in their responses by investing similar amounts of money regardless of information type.

In terms of social inference, one way of interpreting these data is that comparison participants made an inference that the situational information reflected some dispositional trait. For example, given the description that gains were “due to economic growth in China,” perhaps comparison participants may have inferred that this investor was knowledgeable enough to leverage this external factor. Effectively, this would lead to the inference that the situational information reflected a positive, dispositional value. Participants with vmPFC damage did not appear to make this inferential leap and thus invested differentially by information type. This interpretation is consistent with the view that the vmPFC is an important substrate for encoding value from stimuli from various modalities (Rolls, 2000), particularly in relation to social decisions (e.g., Hare et al., 2010).

Interestingly, part of the vmPFC (mesial orbitofrontal cortex) is involved in encoding primary gustatory and olfactory rewards (for a review see Rolls, 2000), and more generally, is involved in perceptual chemosensory processing (Gottfried and Zald, 2005). We suggest that brain regions that are necessary for social inference in humans descend from those used for social evaluation in mammals. In mammals, these social evaluations rely heavily on chemosensation, however, in humans, these social evaluations rely very little, if at all, on chemosensation, and instead require inferences drawn from less reliable sources of information, including multiple sensory modalities, over multiple instances, where interference is more easily introduced from factors including deception, misperception, misapprehension, and loss/lack of attention might mitigate the reliability and consistency of pertinent information (Koscik, 2010; Koscik and Tranel, 2012a). Consequently, the vmPFC may be a critical structure involved in social inference reflecting its conserved role in social evaluation but repurposed for inferential processing. Consistent with these data, we have demonstrated that damage to the vmPFC results in a deficit in transitive inference (Koscik and Tranel, 2012b), which in combination with these results strongly suggest a role for the vmPFC in social inference.

We also find it quite intriguing that under the conditions of this experimental protocol, patients with vmPFC damage actually made more “rational” investments—investments that were, in fact, economically advantageous. When making real-life investment decisions, it is important to dissociate skill, which may relate to increased likelihood of replicating any gains in the future, and luck, which is unlikely to reproduce gains unless uncontrollable elements of the situation remain constant. The conditions in our experiment were controlled such that all information was positive, i.e., all descriptions, either dispositional or situational, involved a gain on the potential investment as did the outcomes of the investments. Under these conditions, comparison participants made less advantageous decisions than did the patients with vmPFC damage. An interesting parallel to this finding was reported by Shiv and colleagues (2005), who found, using a paradigm that was constructed such that long-term outcomes were fiscally positive, that patients with damage to the vmPFC had better fiscal outcomes than did normal, healthy participants (interpreted as due to absence of normal emotions in the vmPFC patients, in the experiment used by Shiv et al.).

If the pattern of investing more when given dispositional information were to be replicated under conditions where money is lost on the investments, the vmPFC participants would likely lose more money than the comparison participants by investing too much with partners who are likely to lose more in the future. This interpretation is consistent with the “error management theory” of Haselton and Buss (2000). Essentially the correspondence bias did not evolve in normal individuals as a means to maximize gains; rather introducing this systematic bias reduces the likelihood of falling prey to large, consequential errors and losses at the cost of absorbing small but less consequential losses. We constrained our initial exploration into this topic to positive gains only to reduce the impact of the potentially confounding influence of loss aversion, for which the vmPFC has been implicated (Tom et al., 2007), and a definitive answer to this question awaits extrapolation to investment losses. Additional research is needed to explore the role of causal attributions when information is negative, to examine whether or not this strategy helps normal adults avoid potentially greater losses.

Our data are consistent with the notion that vmPFC is part of a neural system important for automatic identification of emotional significance from stimuli (Phillips 2003). Damage to the vmPFC disrupted a portion of the system where automatic, obligatory, dispositional attributions are made for all incoming information. In contrast, the neural systems responsible for making controlled, regulatory appraisals to correct for initial biases were left intact, where the dmPFC appears to be a critical component (Philips 2003). It is important to note that additional brain regions are most likely involved in a larger neural system necessary for achieving the complex processing necessary for successful social evaluation, though a full survey is well beyond the scope of our discussion. Given that vmPFC and dmPFC may be critical, complementary nodes in the neural systems necessary for normal attributional processes, it is intriguing that the dmPFC has been implicated in social attribution as well. For example, Mitchell and colleagues (2006) report that dmPFC is activated for both trait diagnostic and non-diagnostic information when explicitly forming impressions; however, when participants were not explicitly forming impressions, the dmPFC was activated to a greater extent for trait diagnostic information. These findings are consistent with the idea that people automatically make dispositional attributions (involving the vmPFC) and only engage in deeper processing to include situational information as an explicit, controlled process (involving the dmPFC) (for a review see Gilbert & Malone 1995). Assuming that the regulatory process is inadequate to completely correct for initial biases, normal behaviour constitutes the correspondence bias. In the case of vmPFC damage, no initial, dispositional attribution is made at all, leaving only the more accurate controlled process and thus more accurate attributions, consistent with our results.

The vmPFC is not a unitary structure, but rather, encompasses a large swath of cortical territory and includes several cytoarchitectonically-distinct subregions. Our exploratory analysis suggested that subgenual and medial orbitofrontal regions (including the straight gyrus) may be two intriguing target regions as opposed to lateral orbitofrontal cortex which may be unrelated to attributional processes. These exploratory results are limited because of the small sample sizes and uneven distribution of lesions across subregions, and further research is needed to address more definitively whether certain subregions of the vmPFC are especially important for various aspects of attributional processes.

In conclusion, we observed that the vmPFC was critical for making normal social attributions in the context of investment decisions. Participants with vmPFC damage actually made more economically “rational” decisions, by investing more following trait diagnostic, dispositional information than when given non-diagnostic, situational information. Overall, given that normal healthy adults over-use situational information, our data suggest that people could benefit from being aware of the correspondence bias, and reassess their evaluations of positive information in order to optimize their fiscal decisions.

Acknowledgments

This work was supported by the National Institute of Neurological Disorders and Stroke (D.T., P50 NS19632); National Institute on Drug Abuse (D.T., R01 DA022549); and the Natural Sciences and Engineering Research Council of Canada Postgraduate Scholarship (T.R.K., NSERC PGS-D).

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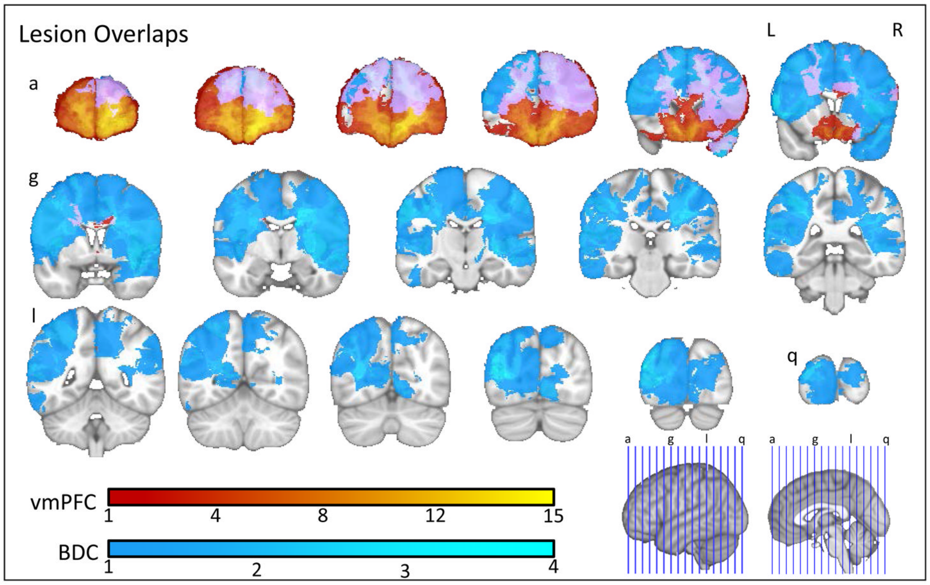

Figure 1.
Lesion Overlaps. Lesions of participants in the vmPFC group are shown in the warm colours, where the maximum overlap (15) is within ventromedial prefrontal sector. Lesions in the BDC group cover a much broader swath of cortical territory with a maximum overlap of 4. Purple represents regions of overlap between the vmPFC and BDC groups, and covers bilateral dorsal PFC.

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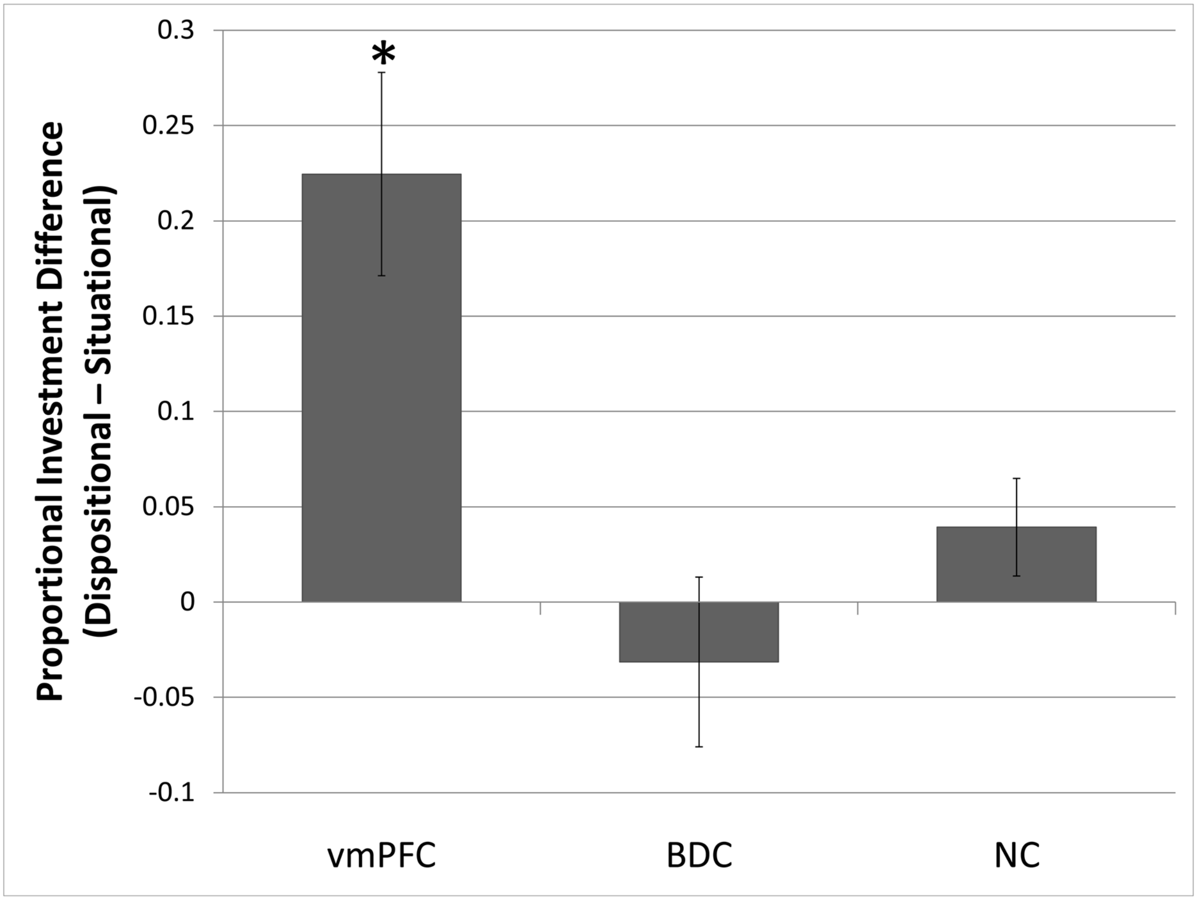

Figure 2.
Difference in Proportional Investment by Group. Bars represent the difference in the proportion of money invested when given dispositional information minus situational information. Participants with vmPFC damage displayed a greater difference than the other groups.

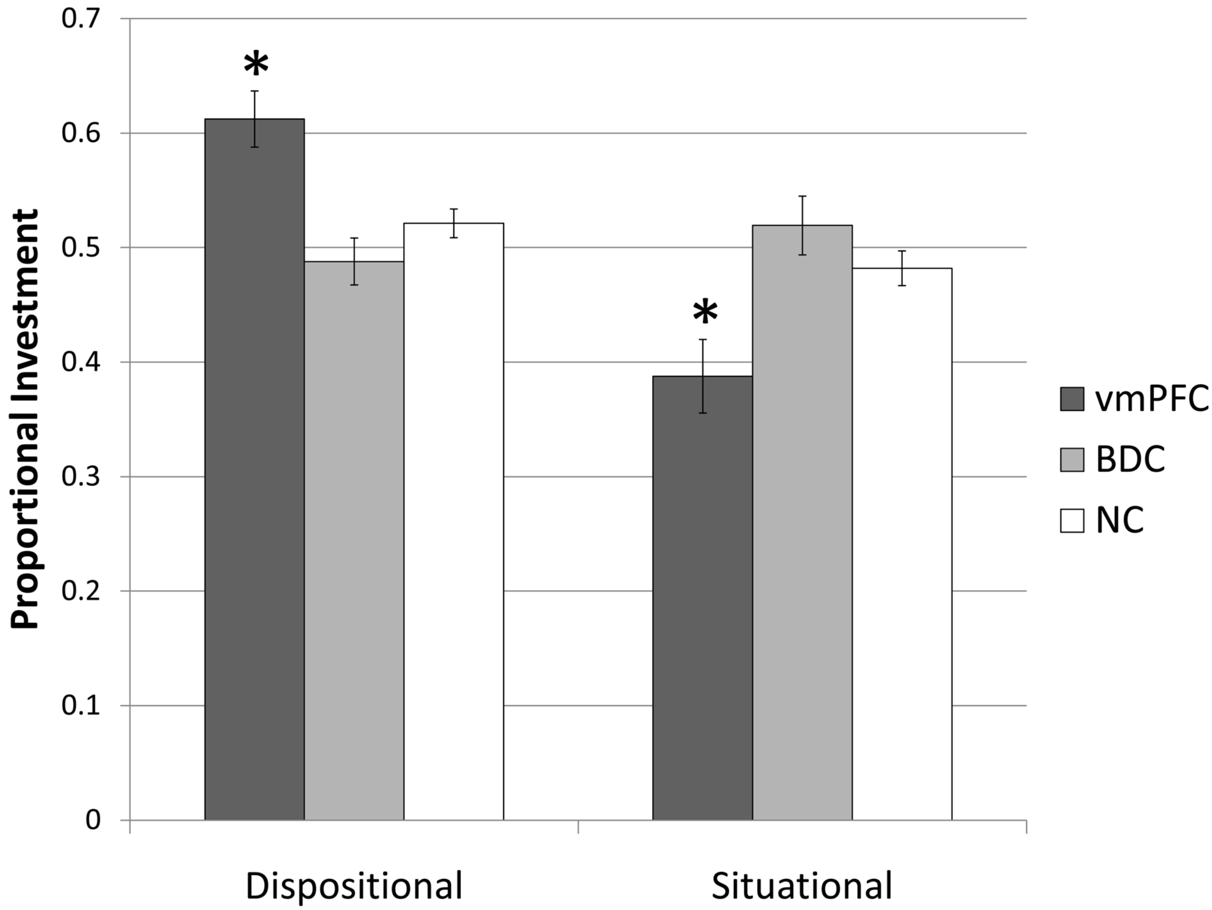

Figure 3.
Proportional Investment by Information Type. Bars represent the proportion of money invested with dispositional or situational information types. Participants with vmPFC damage invested more with dispositional information and less with situational information compared to the other groups.

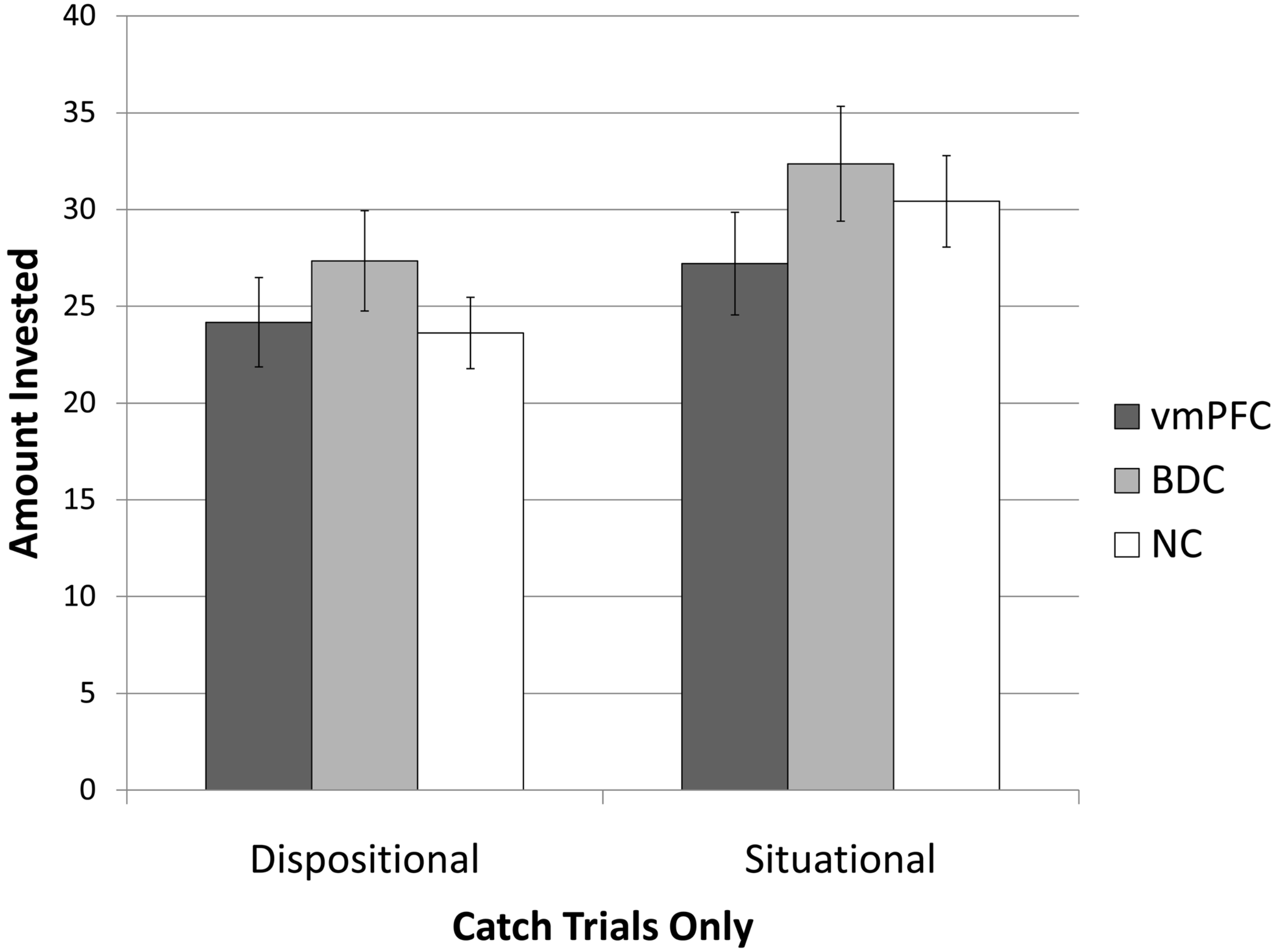

Figure 4.
Investments for Catch Trials. Bars represent the amount invested for dispositional and situational information types on trials where only one of these types of information was given. There are no differences between groups.

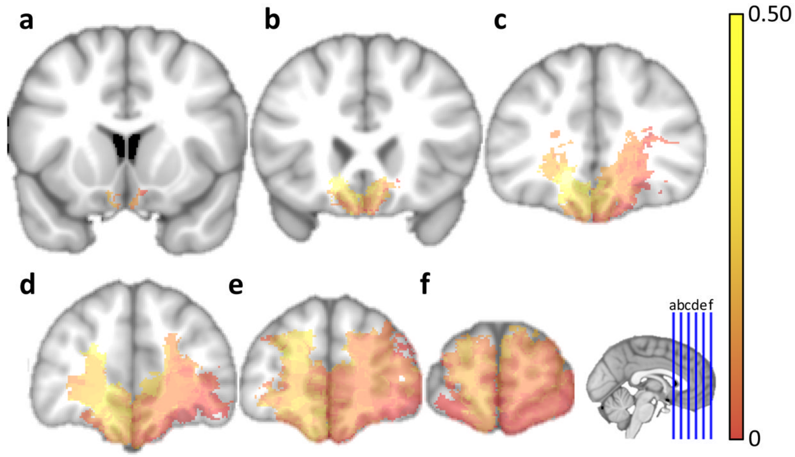

Figure 5.

Specificity of vmPFC subregions. Each voxel represents the group average difference in the proportion of money invested with dispositional and situational information (dispositional – situational) for participants whose lesion includes that voxel. Warmer colours represent a larger difference. Only voxels where the number of lesion overlaps is greater than 5 are included.

Table 1

Demographics and Neuropsychology

		vmPFC	BDC	NC
	N (Men, Women)	17 (10, 7)	30 (17, 13)	45 (22, 23)
	Handedness (R, L, M)	16, 0, 1	23, 2, 5	41, 4, 0
	Age (years)	60.3 (14.9)	57.5 (13.4)	61.7 (13.3)
	Education (years)	13.7 (1.9) *	14.9 (3.0)	16.2 (2.5)
	Chronicity (years)	12.1 (9.0)	15.0 (12.0)	-
	FSIQ	106.6 (11.4)	105.3 (13.4)	-
	PIQ	107.2 (11.3)	105.0 (14.8)	-
WAIS-R	VIQ	105.7 (14.2)	105.7 (16.7)	-
	BDI	3.9 (5) *	8.1 (5.8)	-
	BAI	4.4 (3.6)	6.0 (4.2)	-
	AVLT	13.8 (2.3)	14.0 (1.6)	-
	WCST	4.9 (2.1)	5.5 (1.3)	-
	Face Disc.	44.7 (3.7)	45.9 (4.2)	-
	COWA	39.0 (12.0)	38.5 (12.0)	-
	BNT	55.4 (4.2)	54.8 (6.9)	-

Mean (Std. Dev.)

* $p < 0.05$

Handedness: R = Right handed, L = Left Handed, M = Mixed Handed WAIS = Wechsler Adult Intelligence Scale – III; FSIQ = Full Scale Intelligence Quotient; PIQ = Performance Intelligence Quotient; VIQ = Verbal Intelligence Quotient; BDI = Beck Depression Inventory-II; BAI = Beck Anxiety Inventory; AVLT = Auditory Verbal Learning Test, 30 minute delayed recognition, # correct responses/15; WCST = Wisconsin Card Sorting Test, # of categories completed; Face Disc. = Benton Facial Discrimination Test, raw scores; COWA = Controlled Oral Word Association Test, raw scores; BNT = Boston Naming Test, raw scores (out of 60 maximum). For all neuropsychological measures, references can be found in Tranel (2009).

Table 2

Descriptions

Description 1	Description 2
due to increased rates of higher education.	*because he is a risk-taker.
due to a rise in commodity prices.	because of the expansion of green technologies.
due to economic growth in China.	*because he is goal-oriented.
*because he is highly motivated and ambitious.	because of the decrease in trade tariffs.
*because he is a conservative investor.	due to a recent scientific breakthrough.
*due to his extensive education.	*due to his hard-working nature.
due the rise in internet stock trading.	because of a rise in the level of tourism.
*because he is very good at solving problems.	*due to his unbiased opinions.

*Connotes dispositional descriptions.