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A neuropsychological investigation of decisional certainty

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Abstract

The certainty that one feels following a decision increases decision-making efficiency, but can also result in decreased decision accuracy. In the current study, a neuropsychological approach was used to examine the impact of damage to the ventromedial prefrontal cortex (vmPFC) on core psychological processes promoting decision certainty: selective exposure, overconfidence, and decisiveness. Given previous research demonstrating that vmPFC damage disrupts the generation of negative emotional (somatic) states that have been associated with selective exposure and overconfidence, it was hypothesized that damage to the vmPFC would disrupt engagement in selective exposure, decrease overconfidence, and increase indecision. Individuals with vmPFC damage exhibited increased indecision, but contrary to our hypothesis, engaged in similar levels of selective exposure and overconfidence as the comparison groups. These results indicate that indecision may be an important psychological mechanism involved in decision-making impairments associated with vmPFC injury. The results also suggest that the vmPFC may not be critical for selective exposure or overconfidence, which provides support for a recent “desirability” account of selective exposure.

Keywords

selective exposure; information seeking; overconfidence; decisiveness; ventromedial prefrontal cortex; brain damage

1. Introduction

Feeling certain about the decisions we make is a double-edged sword. On the one hand, decision certainty can increase decision-making efficiency and reduce the negative, uncomfortable arousal that results from uncertainty or from considering that we might have made the wrong decision (Harmon-Jones, Amodio, & Harmon-Jones, 2009). On the other

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hand, decision certainty can lead us to engage in increased confirmatory information seeking (selective exposure; Hart, Albarracín, Eagly, Bechman, Lindberg, & Merrill, 2009); to think that our decisions are correct and that outcomes linked to our decisions are more likely than is warranted (overconfidence; Moore & Healy, 2008); and to spend less time evaluating new decision-relevant information (decisiveness; Webster & Kruglanski, 1994); all of which undermine our ability to objectively reassess the quality of our decisions to guide future decision making (e.g., Kray & Galinsky, 2003; Schulz-Hardt, Jochims, & Frey, 2002). Despite the literature examining these core psychological processes involved in decision certainty and the implications of decision certainty in a wide variety of contexts—from business (e.g., Karlsson, Loewenstein, & Seppei, 2009) to politics (e.g., Knobloch-Westerwick, 2012) to medicine (e.g., Kostopoulou, Mousoulis, & Delaney, 2009)—the underlying neural mechanisms are unknown.

The current study tested whether the ventromedial prefrontal cortex (vmPFC) is a key neural substrate underlying decision certainty. The vmPFC, which includes Brodmann areas 10, 14, 25, 32, and sections of Brodmann areas 11-13, is extensively connected to structures in the limbic system (i.e., amygdala, hippocampus, and insula), hypothalamus, and brain stem (Öngür & Price, 2000; Rolls, 2000). Individuals who sustain damage to the vmPFC are remarkable in that they exhibit relatively intact intellectual functioning, yet have deficits in complex decision making, resulting in atypical decisions and judgments in the economic, social, and moral domains (e.g., Anderson, Bechara, Damasio, Tranel, & Damasio, 1999; Bechara, Damasio, Tranel, & Damasio, 1997). These decision-making deficits have been posited to result from disruption in the integration of emotional responses (somatic markers) into decision making (Damasio, 1994).

It is this disruption in the integration of emotional responses into decision making that underlies the hypothesis that the vmPFC may be a critical neural substrate for in decision certainty. Experimental psychologists have argued that defense motivation, a motivation to avoid the negative emotional (somatic) state that results from being wrong or seeing indications that one is wrong, plays a key role in processes involved with decision certainty, such as selective exposure (Hart et al., 2009; Jonas, Schulz-Hardt, Fischer, & Frey, 2006; Smith, Fabrigar, & Norris, 2008). Negative somatic states associated with defense motivation include anticipated regret (e.g., Zeelenberg, 1999), embarrassment or guilt (e.g., Higuchi & Fukuda, 2008), and cognitive dissonance (e.g., Zanna & Cooper, 1976). Consequently, if damage to the vmPFC disrupts the negative emotional states that drive processes that increase decision certainty, like selective exposure, then damage to the vmPFC should lead to decreased decision certainty.

Several lines of evidence from neuroimaging and lesion studies suggest that the vmPFC is involved in processes related to decision certainty, such as affective states related to defense motivation, processing belief-inconsistent information, and decisiveness.

First, lesion and neuroimaging studies support the involvement of the vmPFC in experiencing the negative affective states associated with defense motivation, such as guilt and embarrassment (Krajcich, Adolphs, Tranel, Denburg, & Camerer, 2004; Takahashi, Yahata, Koeda, Matsuda, Asai, & Okubo, 2004) or anticipated regret (Anderson et al., 1999;

Camille, Coricelli, Sallet, Pradat-Diehl, Duhamel, & Sirigu, 2004). Defense motivation is hypothesized to drive engagement in selective exposure and subsequent feelings of overconfidence (e.g., Smith et al., 2008). Consequently, this research would be consistent with a role for the vmPFC in selective exposure and overconfidence, decision processes that, when intact, serve to solidify one's decision certainty.

Second, neuroimaging studies have shown increased vmPFC activation during the comparison of different options (Boorman, Behrens, Woolrich, & Rushworth, 2009; Chau, Kolling, Hunt, Walton, & Rushworth, 2014) and when participants passively view belief-inconsistent information (Kato, Ide, Kabashima, Kadota, Takano, & Kansaku, 2009; Westen, Blagov, Harenski, Kilts, & Hamann, 2006). Increased vmPFC activation is also associated with attitude perseverance in the face of conflicting information (Kato et al., 2009). These studies suggest that the vmPFC may be involved in evaluation of relative evidence and devaluing of disconfirmatory information in order to maintain decision certainty, a process which has been repeatedly demonstrated in the psychological literature (e.g., Fischer, Fischer, Weisweiler, & Frey, 2010).

Third, it has been observed that individuals exhibit increased indecisiveness following injury to the vmPFC (Anderson, Barrash, Bechara, & Tranel, et al., 2006; Barrash, Tranel, & Anderson, 2000). For example, in the classic report of patient E.V.R., Eslinger and Damasio (1985) note that "Deciding where to dine might take hours, as he discussed each restaurant's seating plan, particulars of menu, atmosphere, and management" (p. 1732). However, these observations have not been consistently replicated in the few experimental studies of decision timing in vmPFC patients (Ciaramelli, Muccioli, Làdavas, & di Pellegrino, 2007; Fellows, 2006; Rogers, Everitt, Baldacchino, Blackshaw, Swainson, Wynne, ... Robbins 1999; Young, Bechara, Tranel, Damasio, Hauser, & Damasio, 2010). One study to find increased decision times in patients with orbitofrontal damage (Rogers et al., 1999) used a task in which participants indicated decision certainty by betting on their choice. Given the predictable structure of the task (choice followed by a bet with the same betting options each time), prior to entering choices participants may have already been evaluating their post-decisional certainty (i.e., "deliberating" their bet), suggesting reduced decision-certainty may account for the increased response time. Decision certainty is also readily observed in the real world, where one may hem-and-haw, making a choice and re-evaluating it, precisely where increased indecision has been reported in vmPFC patients. If reports of indecisiveness due to vmPFC injury are indicative of diminished decision certainty, as predicted here, this could be captured in longer reaction times in the post-decisional (but not pre-decisional) phase.

To summarize, the vmPFC plays a critical role in generating the negative somatic markers associated with defense motivation in response to decision-inconsistent information, which is thought to drive selective exposure and overconfidence. Additionally, evidence that vmPFC damage increases indecisiveness suggests that the length of time for deciding which information to read may be affected by vmPFC damage. We predict that damage to the vmPFC will diminish processes of post-decisional certainty: selective exposure, overconfidence, and decisiveness.

2. Material and Methods

2.1 Participants

A group of nine individuals with bilateral vmPFC damage (vmPFC group) and ten brain-damaged comparison individuals (BDC group) were recruited from the Patient Registry of the University of Iowa's Division of Behavioral Neurology and Cognitive Neuroscience. The BDC group contained only individuals with brain lesions located outside the vmPFC and other emotion-related areas, such as the limbic system and insula. The two groups were comparable on demographic variables and chronicity (time since lesion onset), and all patients were tested in the chronic epoch, three or more months post-lesion onset (Table 1). A group of 15 neurologically normal comparison participants (NC group) was recruited from the local community (Table 1). The only significant difference between the three groups was in education, $F(2,31) = 6.34, p = .005$. Post-hoc comparisons revealed that the vmPFC group had overall lower education than the two comparison groups, $ps < .02$. However, there was no main effect or significant interactions with education on the main dependent variables, so it will not be discussed further, $F_s < 1.5$. The neuropsychological profiles of individuals in the vmPFC group revealed generally intact performances on standard intelligence and neuropsychological tests (Table 2). This research was approved by the University of Iowa Internal Review Board.

2.2 Experimental methods and materials

2.2.1 Experimental methods—Participants completed a modified version of an aesthetic prediction task used in previous selective exposure research (e.g., Windschitl, Scherer, Smith, & Rose, 2013). During this task, participants viewed two works of art (e.g., two paintings) and predicted which of the two artworks was preferred by more people nationwide. Following their prediction, participants selected information to read about the artworks from an “information buffet” (see *Experimental materials*). Following their information selections, participants indicated the likelihood that their prediction was correct, as a measure of prediction confidence. After participants completed the above procedure for four artwork pairs (in order of presentation: photographs, paintings, sculptures, and songs), participants read the full version of the comments they had selected and made a second confidence judgment.

2.2.2 Experimental materials—Each information buffet was composed of eight titles (see Figure 1 for an example). Each title was a positive or negative evaluative summary of a full comment written about one of the artworks (e.g., “Mountain Photo is a well detailed photo.”) ostensibly written by a person from Iowa who had viewed the artwork, with each title presumably from a different person. Participants were instructed to select one to seven of the titles for the comments that they would like to read later (in its full form). Critically, there were two positive and two negative titles for each of the two artworks. Consequently, regardless of which artwork was selected by a participant, participants viewed four titles that were consistent with their prediction (two positive toward the artwork they predicted, two negative toward the artwork they did not predict) and four titles that were inconsistent with their prediction (two negative toward the artwork they predicted, two positive toward the

artwork they did not predict). The titles were presented in random order for each participant and were sequentially presented to participants prior to viewing the information buffet.

2.3 Analyses

2.3.1 Neuroanatomical analysis—The neuroanatomical analysis of vmPFC patients (Figure 2) was based on magnetic resonance data for six participants and on computerized tomography data for the other three participants. All neuroimaging data were obtained in the chronic epoch. Lesions for vmPFC patients were reconstructed in three dimensions using Brainvox (Frank, Damasio, & Grabowski, 1997; Damasio & Frank, 1992). Using the MAP-3 technique described by Damasio, Tranel, Grabowski, Adolphs, and Damasio (2004), each lesion contour was manually warped into a normal template brain. The overlap of lesions in this volume, calculated by the sum of N lesions overlapping at any single voxel, is color coded in Figure 2 and shows the maximal region of overlap in the vmPFC.

2.3.2 Data analysis—To determine the amount of selective exposure individuals engaged in, a selection bias index was calculated by dividing the number of titles selected to read that were consistent with a participant's prediction (i.e., positive towards the selected artwork or negative towards the non-selected artwork) by the total number of titles selected. Consequently, a value of 50% would indicate an unbiased search, while values greater than 50% reflect a bias towards selecting confirming information and values less than 50% reflect a bias towards seeking disconfirmatory information. To calculate overall effects, composite scores were calculated for selective exposure and confidence estimates by taking the average of the values for each artwork-type. Preliminary analyses revealed the presence of two outliers (± 2 SD above the mean), one from the BDC group who had selection bias indices of 100% on all four information selection tasks and one from the NC group who had selection bias indices of 0% for all four information selection tasks. These patterns are suggestive of atypical data as it is rare to see such responses. Due to their atypical response patterns and the bias that such extreme outliers introduce in small samples, these outliers were dropped from subsequent analyses although including them did not change the findings.

To test for overall selective exposure and overconfidence effects across the whole sample the composite values for each of these was analyzed using a one-sample t-test with test values of 50%. Mixed-model ANOVAs were used to analyze whether there were any differences in the total number of titles selected and average reading times between group, with artwork-type as a within-subject factor and group as a between-subjects factor.

Two sets of analyses were then performed. First, to determine if brain injury *per se* affected decision certainty we compared the NC and BDC groups on each measure. Second, the lack of systematic differences (see Results) led us to combine these two comparison groups into one overall comparison group to increase the power of subsequent analyses with the vmPFC group. Dependent variables examined in these analyses were selection bias index; confidence estimates; and response times for predictions, information selections, and confidence estimates. Each analysis included artwork-type as a within-subject factor and group as a between-subjects factor. Since participants made two confidence estimates for

each artwork-type, the placement of the confidence estimate was included as an additional within-subject factor for the confidence estimate analysis. Preliminary analyses revealed group differences in reading times (see Results), so reading time was included as a covariate for the response time analyses.

3. Results

Before delving into the main results, there are some general results across the whole sample worth noting. First, participants engaged in selective exposure. As a reminder, since there were equal numbers of consistent and inconsistent information available to select, an unbiased search would yield a selection bias index of 50%. The mean selection bias index across all participants was 58.6% ($SD = 13.0$), representing a biased selection of choice consistent information, $t(31) = 3.75$, $p = .001$, $d = 0.66$. While our metric of selective exposure controls for differences in total number of titles selected it is worth noting that there were no group differences in number of titles selected, $F(2, 29) = 0.88$, $p = .42$, $\eta_p^2 = .06$, with participants selecting between three to four titles ($M = 3.6$, $SD = 1.6$) on average.

Second, participants exhibited significant levels of overconfidence. The use of unfamiliar stimuli means participants would have no prior knowledge that would be useful for determining which of the two artworks was actually preferred by others. For this reason, a normative response on the confidence estimates would be 50% (equally likely that either artwork was preferred nationwide). The average first confidence estimates was 65.2% ($SD = 11.3$), $t(31) = 7.6$, $p < .001$, $d = 1.35$, and the average second confidence estimate was 64.9% ($SD = 12.4$), $t(31) = 6.8$, $p < .001$, $d = 1.20$, representing unwarranted optimism that their predictions were correct.

Third, we also tested whether there were any group differences in overall reading times that would need to be controlled for in other response time analyses. There were significant group differences, $F(2,29) = 7.19$, $p = .003$, $\eta_p^2 = .33$, with post-hoc tests revealing a general effect of brain injury, with average time to read the full comments much shorter for the NC group compared to the BDC group, $p = .001$, $d = 1.21$, and vmPFC group, $p = .05$, $d = 1.51$ (see Table 3 for means). Due to these differences in reading times, average reading time was included as a covariate for analyses involving response times.

Turning to our main analyses, we first determined whether there were any differences between the comparison groups to determine if brain injury *per se* affected any of the experimental dependent measures. The NC and BDC groups did not differ significantly in their selective exposure, $F(1,21) = 3.00$, $p = .10$, $\eta_p^2 = .13$, confidence estimates, $F(1,21) = 2.14$, $p = .16$, $\eta_p^2 = .09$, their time to make predictions, $F(1,20) = 0.35$, $p = .56$, $\eta_p^2 = .02$, time to select comments to read, $F(1,20) = 0.04$, $p = .84$, $\eta_p^2 = .002$, or time to make confidence estimates, $F(1,20) = 0.21$, $p = .65$, $\eta_p^2 = .01$. In short, there were no overall systematic differences between the NC and BDC group, and they are thus combined for the sake of comparison to the vmPFC group.

Contrary to our hypothesis, selective exposure was not significantly reduced in individuals who had vmPFC damage, $F(1, 30) = 0.07$, $p = .80$, $\eta_p^2 = .002$. To the contrary, participants

with damage to the vmPFC had a mean selection bias index ($M = 59.6\%$, $SD = 14.0$) that was essentially the same as the comparison group ($M = 58.2\%$, $SD = 12.9$). Similar results were found for the overconfidence measures. Our analyses revealed no differences in confidence between the two groups, $F(1, 30) = 1.39$, $p = .25$, $\eta_p^2 = .04$, and there was no significant interaction between the two groups based on whether it was the first or second confidence estimate, $F(1, 30) = 0.64$, $p = .43$, $\eta_p^2 = .02$. Similar to selective exposure, the first ($M = 69.7\%$, $SD = 14.9$) and second ($M = 68.2\%$, $SD = 17.9$) confidence estimates for the vmPFC group was similar to the first ($M = 63.5\%$, $SD = 9.4$) and second ($M = 63.7\%$, $SD = 9.6$) confidence estimates of the comparison group. The fact that damage to the vmPFC did not disrupt selective exposure or overconfidence effects suggests that the vmPFC is not a critical neural substrate for selective exposure or overconfidence.

The response time results were consistent with our hypotheses. There were no group differences in time to make predictions (re: the first decision for a round), $F(1, 29) = 0.02$, $p = .89$, $\eta_p^2 = .001$, and no group by round interaction, $F(3, 87) = 1.19$, $p = .32$. There was a significant finding for round, $F(3, 87) = 3.34$, $p = .02$. While there was a significant increase in average time to make a prediction from Round 1 to Round 2 (diff = 5.13 seconds), $p = .02$, indicating an increase in pre-decisional deliberation, these times decreased from Round 2 to Round 3 (diff = -3.10 seconds), $p = .20$, and from Round 3 to Round 4 (diff = -6.06 seconds), to the point that the average time to make a prediction for Round 4 was significantly lower than all three previous rounds, $ps < .005$, with the average time to make a prediction for Round 4 being 4.57 seconds shorter than the Round 1 time, $p = .005$ (see Figure 3). While there were no significant differences between the vmPFC and comparison groups in how long it took them to make their predictions, or their confidence estimates, $F(1, 29) = 0.76$, $p = .39$, $\eta_p^2 = .03$, the groups did differ in how long it took them to select the titles they wanted to read, $F(1, 29) = 4.04$, $p = .05$, $\eta_p^2 = .14$ (Figure 3). Specifically, and consistent with our predictions, the vmPFC group took significantly longer to select titles ($M = 51.6$, $SD = 26.0$) than the comparison group ($M = 36.0$, $SD = 15.5$). Moreover, while participants in the comparison groups became relatively more efficient in selecting titles as the study progressed, taking less time to select the titles to the comments they wanted to read, the vmPFC group actually took longer to select titles as the study progressed, taking significantly longer to select titles than the comparison group, $F(3, 87) = 3.56$, $p = .02$, $\eta_p^2 = .11$ (see Figure 3). It is worth noting that these results hold up even when the previously excluded outliers are included in the analysis, $F(1, 31) = 4.69$, $p = .04$, $\eta_p^2 = .13$. The vmPFC group mean was influenced by one participant in particular. If this participant's data is excluded from analyses, the vmPFC group still takes longer to select comments to read ($M = 44.6$ seconds, $SD = 16.3$) than the comparison group ($M = 36.0$ seconds, $SD = 15.5$), but not significantly so, $F(1, 28) = 1.71$, $p = .20$, $\eta_p^2 = .06$, but this could simply be from the significant decrease in power due to dropping one participant in the vmPFC group being 11% of that group. Additionally, given that this participant is in our target group—a necessarily small group given the rarity of bilateral vmPFC damage—qualitatively they may be better seen as an “affected individual” rather than an “outlier.” A repeated-measures ANOVA looking at pre- and post-decisional response times across rounds and across groups revealed a significant three-way interaction, $F(3, 87) = 3.42$, $p = .02$, $\eta_p^2 = .11$. This three-way interaction is best interpreted via our description of the earlier results: there were no

significant differences between the two groups in pre-decisional responses times, but the differences in post-decisional response times between the two groups increased from round to round (see Figure 3). Overall, these results provide evidence for increased post-decisional deliberation for individuals with vmPFC damage.

4. Discussion

The current study found that damage to the vmPFC resulted in diminished post-decisional certainty, specifically reduced decisiveness when evaluating one's choice, but intact selective exposure and overconfidence.

After making a choice, the vmPFC group exhibited indecisiveness, taking significantly longer to evaluate and select decision-relevant information than the comparison group. As noted earlier, individuals with vmPFC damage and their collateral informants report increased indecisiveness in the real-world following the injury, but, to our knowledge, this is the first empirical demonstration of this effect and its basis in impaired post-decisional certainty in patients with bilateral vmPFC injury. A prior study did find increased decision times in patients with orbitofrontal injuries, but did not explore the pre- or post-decisional origin of the effect in the decision-making process (Rogers et al., 1999). Relatedly, one potential counter-explanation of our results is that individuals in the comparison group engaged in increased pre-decisional deliberation as the study progressed, leading to shorter times to select comments to read. If true, this would suggest that damage to the vmPFC does not increase post-decisional indecisiveness, but fails to increase pre-decisional deliberation. This explanation is unlikely though. First, in this task increased pre-decisional deliberation is not likely to have an impact on time to select post-decisional information because the options (information) vary for each trial and thus participants do not know what options they will be presented with, and must selection information in the “post-decisional moment”. Second, the time to make a prediction do not support this hypothesis. Rather than taking longer to make their initial decisions, participants actually took less time to make their initial decisions as the study progressed (see Figure 3). This provides evidence that participants did not exhibit an increase in pre-decisional deliberation. Consequently, our findings suggest the increase in decision time to select comments to read may be due to post-decisional indecisiveness. The vmPFC and comparison groups did not differ in response timing for other components of the task, and the difference in response times to select comments cannot be accounted for by differences in reading speeds, since these results controlled for differences in reading time, or increased pre-decisional deliberation, since there were no group differences in pre-decisional deliberation and pre-decisional deliberation actually decreased as the study progressed.

One factor that we did not explore in the present study is the complexity of post-decisional information selection. While there was no “optimal” choice in the current study, it is worth noting that after making their choice, which always consisted of two options, participants were presented with eight choice-relevant information options. While previous research has demonstrated that vmPFC function is involved in decision-making in the context of multiple options (Chau et al., 2014; Noonan, Walton, Behrens, Sallet, Buckley, & Rushworth, 2010), other studies have shown that vmPFC injury does not alter initial decision times even for

complex choices (Fellows, 2006). The data in the current study are consistent with the notion that vmPFC patients' impairment in decision certainty may emerge in more complex post-decisional situations, as in the post-choice bets (5 options) made in the study by Rogers and colleagues (1999), and as in the real world where many post-decisional options are often available. Damage to the vmPFC may disrupt the evaluation of options in complex contexts such as post-decisional information evaluation where it results in indecisiveness. Future studies should more systematically explore the interplay between complexity and post-decisional processes, for example to test whether vmPFC patients show intact decisiveness in simpler or more constrained post-decisional contexts.

Contrary to the hypothesis that damage to the vmPFC should reduce or eliminate individuals' engagement in selective exposure and overconfidence, individuals with lesions to the vmPFC exhibited similar levels of selective exposure and overconfidence as individuals in the comparison groups, suggesting that the vmPFC is not critical for selective exposure or overconfidence. Given the prominence of defense motivation as the source of selective exposure in the psychological literature and the role of the vmPFC in the generating the somatic markers associated with defense motivation, how might one account for the results of the current study? One could interpret these negative findings as suggesting the vmPFC is not critical for the somatic marker functions involved in selective exposure, although this would run counter to evidence for the vmPFC's role in defense motivation. A stronger interpretation may be that somatic marker functions are not, in fact, essential to selective exposure as was previously thought. Indeed, there has been some recent evidence that suggests that selective exposure can also be the result of a different motivation: desirability. Being right, or seeing indications that one might be right, can be affectively rewarding. To induce this rewarding affective state, individuals might seek out information that suggests that they might be right, resulting in selective exposure (see Scherer, Windschitl, & Smith, 2013, for a description and preliminary evidence for these claims).

Consistent with the desirability account of vmPFC patients' intact selective exposure, previous neuropsychological research has demonstrated that individuals with lesions to their vmPFC demonstrate intact motivation to pursue immediately and unambiguously rewarding outcomes (e.g., Bechara et al., 1997; Bechara, Tranel, & Damasio, 2000; Weller, Levin, Shiv, & Bechara, 2007). While research on stimulus-reward learning and neuroeconomics has demonstrated that the vmPFC is involved in social learning and stimulus-reward learning (e.g., Behrens, Hunt, Woolrich, & Rushworth, 2008; Biele, Rieskamp, Krugel, & Heekeren, 2011) and belief updating (e.g., Asp, Manzel, Koestner, Cole, Denburg, & Tranel, 2012; Doll, Hutchison, & Frank, 2011), damage to the vmPFC does not impair the ability to recognize and seek immediate rewards (see Wallis, 2007, for a review). Other research has indicated that individuals with lesions to the vmPFC persevere on simple behaviors that were previously rewarded, even when the behavior becomes paired with punishments (e.g., Rolls, Hornak, Wade, & McGrath, 1994). Providing additional evidence, both gamblers and healthy participants exhibit decreased vmPFC activation when they engage in gambling, suggesting that decreased vmPFC activation (or outright vmPFC damage) leads to increased reward-seeking at the expense of future negative outcomes (see Clark, 2010 for a review). Taken together, the affectively rewarding nature of confirmatory information coupled with

intact reward seeking following vmPFC damage may account for the results of the current study. Further research is needed to test this alternative explanation.

There are limitations to the current study that are important to mention. Due to the rare occurrence of relatively circumscribed, bilateral brain damage, our samples were small, although consistent with many previous lesion studies using similar kinds of patients. Also, one of the vmPFC patients incurred their injury from trauma, and although detailed anatomical analysis indicates a focal bilateral vmPFC lesion in this patient, we cannot rule out the possibility that there is other, more diffuse damage in this patient that is not evident in neuroimaging. Second, null results can be difficult to interpret, since there are a number of possible reasons for failing to reject the null hypothesis (e.g., low power due to small Ns). That being said, the results of the current study are more consistent with vmPFC damage having no effect on selective exposure and overconfidence than vmPFC damage having an effect. Specifically, whereas vmPFC damage can result in marked deficits in domains that are associated with vmPFC functioning (e.g., social behavior, complex decision making), we did not find evidence of a decrease in selective exposure or overconfidence in the vmPFC group. On the contrary, while not statistically larger, the mean selection bias and confidence of the vmPFC group was directionally larger than the comparison group. A final limitation is that the differences in time to select comments to read between the vmPFC and comparison groups were influenced by one participant in the vmPFC group who had substantially longer selection times. However, while this individual may be an outlier in a statistical sense, they are in our target patient group and thus may simply be an individual affected by their brain injury.

Decision certainty is a double-edged sword. While increasing decision efficiency, decision certainty often comes at the cost of decision accuracy. The current results provide insight into the role of the vmPFC for decision certainty. While there was little evidence that the vmPFC is a critical neural substrate for selective exposure and overconfidence, two processes associated with decision certainty, there was evidence that the vmPFC plays a role in decisiveness. What these studies do emphasize is how little we know about the role of the vmPFC in the processes linked to decision certainty. It is also unclear the extent to which we would expect damage to the vmPFC (or any region of the brain) to result in uniform changes in decision certainty or whether the impact of damage would vary as a function of specific processes and different contextual factors (e.g., time pressure, complexity, etc.). These are issues that have gone relatively unexamined in the neuroscience literature. Decision certainty has implications for every aspect of our lives, from business to politics to our health, highlighting the need for additional neuroscientific and neuropsychological research to examine the role that various brain regions play in the processes involved in decision certainty.

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Figure 1.

Basic procedure for each round. After completing this procedure for all four artwork pairs, participants read the full comments for the titles they selected and then made a second confidence estimate.

Figure 2.

Lesion overlap map for the nine vmPFC patients, showing mesial, ventral, and frontal views of the lesion overlaps. The color bar indicates the number of overlapping lesions at each voxel. The area of maximal overlap lies in the vmPFC.

Figure 3.

Pre-decisional and post-decisional response times (in seconds) averaged across the four rounds and for each round by group. Error bars represent standard error.

Table 1

Demographic and Clinical Data

Patient	Gender	Age	Education	Handedness	Chronicity	Etiology
0318	M	72	14	R	36	Meningioma resection
1983	F	49	13	R	16	SAH
2352	F	64	14	R	13	SAH; ACoA aneurysm
2391	F	66	13	R	12	Meningioma resection
2577	M	72	12	R	13	SAH; ACoA aneurysm
2990	M	23	12	R	18	Focal brain injury from trauma
3350	M	60	18	R	8	Meningioma resection
3534	F	73	12	R	2	Meningioma resection
3591	F	70	12	R	3	SAH
vmPFC, mean (SD)	4M;5F	60.9 (16.1)	13.3 (1.9)	9R	13.4 (10.1)	
BDC, mean (SD)	6M;4F	59.1 (13.8)	16.0 (2.3)	8R;1L;1M	11.7 (8.9)	
NC, mean (SD)	4M;11F	62.6 (8.1)	16.6 (2.4)	11R;1M;3 unknown		

Individual participants are in the vmPFC group. Group mean and SD values for all participants are reported below the individual vmPFC patient data. Age is in years at time of testing. Education is in years of formal schooling. Chronicity is the time between lesion onset and completion of the present experiment, in years. Handedness reports dominant hand preference. Etiology describes the cause of neurological lesion (SAH = subarachnoid hemorrhage; ACoA = anterior communicating artery).

Table 2

Neuropsychological Data for vmPFC Patients

Patient	WAIS-III				WMS-III				BDI-II
	VIQ	PIQ	FSIQ	TT	GMI	WMI	WCST	Stroop	
0318	142	134	143	44	109	124	6	70	0
1983	110	105	108	44	74	105	6	67	5
2352	108	102	106	44	109	124	6	57	1
2391	110	107	109	43	132	102	6	54	4
2577	89	80	84	44	96	88	0	73	7
2990	107*	117*	108*	44	100	97*	6	51	n/a
3350	119	113	118	44	108	118	6	52	3
3534	107*	117*	110*	44	117	127	6	48	3
3591	78*	105*	87*	44	107	91	0	n/a	8

Data from the Wechsler Adult Intelligence Scale-III (WAIS; *WAIS-IV) include verbal IQ (VIQ), performance IQ (PIQ), and full scale IQ (FSIQ), or the corresponding indices from the WAIS-IV (verbal comprehension, perceptual reasoning, full scale IQ). Wechsler Memory Scale-III (WMS) data include the general memory index (GMI) and working memory index (WMI; *WAIS-IV WMI scale). The Token Test (TT) is a measure of verbal comprehension from the Multilingual Aphasia Exam (#/44). The Wisconsin Card Sort Test (WCST) taps reasoning and concept formation (#categories/6 possible). The Stroop test is a measure of response inhibition (T-score on Stroop Color Word Test interference trial). The Beck Depression Inventory-II (BDI-II) is a self-report measure of depression. n/a indicates that the test was not administered.

Table 3

Means Across Each Group

	NC	BDC	vmPFC
Selective Exposure	54.7 (11.0)	63.8 (14.2)	59.6 (14.0)
Confidence Estimate 1	61.3 (10.1)	66.9 (7.8)	69.7 (14.9)
Confidence Estimate 2	61.5 (9.4)	67.1 (9.5)	68.2 (17.9)
Prediction Response Time	13.7 (5.1)	17.2 (5.4)	15.9 (7.9)
Information Selection Response Time	31.5 (13.1)	42.9 (17.1)	51.6 (26.0)
Confidence Estimate 1 Response Time	12.6 (4.1)	17.3 (7.9)	18.2 (12.2)
Confidence Estimate 2 Response Time	10.0 (3.5)	12.6 (5.7)	12.5 (6.0)
Time to Read Comments	12.5 (5.2)	34.1 (23.9)	25.0 (10.5)

Note: NC = Non-brain-damaged comparison; BDC = Brain-damaged comparison. Standard deviations in parentheses.