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Damage to the ventromedial prefrontal cortex is associated with impairments in both spontaneous and deliberative moral judgments

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Abstract

Implicit moral evaluations—spontaneous, unintentional judgments about the moral status of actions or persons—are thought to play a pivotal role in moral experience, suggesting a need for research to model these moral evaluations in clinical populations. Prior research reveals that the ventromedial prefrontal cortex (vmPFC) is a critical area underpinning affect and morality, and patients with vmPFC lesions show abnormalities in moral judgment and moral behavior. We use indirect measurement and multinomial modeling to understand differences in implicit moral evaluations among patients with vmPFC lesions. Our model quantifies multiple processes of moral judgment: implicit moral evaluations in response to distracting moral transgressions (Unintentional Judgment), accurate moral judgments about target actions (Intentional Judgment), and a directional tendency to judge actions as morally wrong (Response Bias). Compared to individuals with non-vmPFC brain damage and neurologically healthy comparisons, patients with vmPFC lesions showed a dual deficit in processes of moral judgment. First, patients with vmPFC lesions showed reduced Unintentional Judgment about moral transgressions, but not about non-moral negative affective distracters. Second, patients with vmPFC lesions showed reduced Intentional Judgment about target actions. These findings highlight the utility of a formal modeling approach in moral psychology, revealing a dual deficit in multiple component processes of moral judgment among patients with vmPFC lesions.

Keywords

Brain lesions; Computational modeling; Decision making; Emotion; Neuropsychology

1. Introduction

When we witness moral transgressions in everyday life, we often have immediate evaluative reactions that the actions or persons in question are morally wrong. These *implicit moral evaluations* are thought to be immediate and unintentional. Over the past two decades,

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reactions to moral transgressions have been widely studied (Monin et al., 2007) and according to many models of moral cognition, are considered foundational to moral development (Haidt, 2001). In the current research, we use implicit measurement and formal modeling to characterize clinical variation in implicit moral evaluations among patients with lesions to an area substantially implicated in the neuroscience of moral cognition: the ventromedial prefrontal cortex (vmPFC; Blair, 2007; FeldmanHall et al., 2014; Koenigs et al., 2007; Shenhav and Greene, 2014; Van Bavel et al., 2015).

Much work in moral psychology has been devoted to understanding the role implicit evaluations play in moral judgment (Haidt, 2001). Many studies suggested trait and state emotions correlate with and predict moral judgments. Yet some of the most convincing evidence that implicit evaluations play a role in moral judgment and moral behavior has emerged from neuropsychological patient populations. In particular, patients with vmPFC lesions—for whom the requisite affective processing appears to be diminished—have been extensively studied to understand the contribution of affect to morality (for review, see Reber and Tranel, in press). If moral outcomes differ among people with compromised affective reactions (such as patients with vmPFC lesions), this suggests implicit affective processes may be integral to moral judgment and behavior (Prinz, 2007).

Early case studies revealed that patients with lesions to the vmPFC exhibited abnormal social behavior (Damasio, 1994; Forbes and Grafman, 2010; for discussion, see Reber and Tranel, in press). One college-educated man, known as EVR, developed several uncharacteristic behaviors after a tumor was removed from his vmPFC, including a tendency to make poor financial decisions and difficulty maintaining employment and relationships (Eslinger and Damasio, 1985). Such patterns have been exhibited by other patients with vmPFC lesions (Anderson et al., 2006; Barrash et al., 2000; Damasio et al., 2012). Intriguingly, these behavioral differences coincided with intact social knowledge, as EVR and others with similar lesions could explicitly indicate the behaviors that society considers morally appropriate (Saver and Damasio, 1991). Previous research suggested these moral behavior deficits resulted from affective deficits, as patients with vmPFC lesions exhibited diminished affective responding to social stimuli (e.g., Hornak et al., 1996; Leopold et al., 2011; Shamay-Tsoory et al., 2003, 2005; Shamay-Tsoory and Aharon-Peretz, 2007), particularly to depictions of harm (Damasio et al., 1990). These deficits impair not only social behavior, but also rational decision-making (Bechara et al., 1996, 1997; Camille et al., 2011; Hogeveen et al., 2017; Moretti et al., 2009; Reber et al., 2017; for reviews, see Bechara et al., 2000; Forbes and Grafman, 2010; Reber and Tranel, in press; Schneider and Koenigs, 2017).

These affective and moral behavior deficits suggest that vmPFC-dependent affective responses may be important for exhibiting typical patterns of moral judgment and behavior. Furthermore, fMRI studies have revealed that activity in the vmPFC is correlated with responses to moral transgressions (Greene et al., 2001, 2004; Schaich Borg et al., 2006). This association between vmPFC and moral judgment has been replicated across multiple neuroimaging (Decety and Cacioppo, 2012; Decety et al., 2012) and psychophysiological (Moretti et al., 2010) measures. Further neuropsychological studies revealed that patients with vmPFC lesions also exhibited atypical responses to moral dilemmas involving high

conflict between deontological and utilitarian moral principles (e.g., killing one person to save five people; Koenigs et al., 2007; Ciaramelli et al., 2007; Thomas et al., 2011; Taber-Thomas et al., 2014) and atypical patterns of third-party punishment (Glass et al., 2015). Recent work finds that vmPFC lesions shape religious beliefs (Zhong et al., 2017) and political beliefs (Cristofori et al., 2015). Overall, the extant literature suggests the vmPFC mediates affective influences on moral judgment (Blair, 2007; Ciaramelli and di Pellegrino, 2011; Greene, 2007; Koenigs et al., 2007; Croft et al., 2010; Shenhav and Greene, 2014; Young and Saxe, 2008, 2009).

Much prior work on moral judgment examined how patients respond to sacrificial dilemmas pitting competing moral principles against each other. The current work expands upon this previous work in multiple ways. First, no prior research has used implicit measures of social cognition to understand how vmPFC deficits contribute to moral judgment. As patients with vmPFC lesions often show intact explicit moral judgments, measures which bypass self-report, such as implicit measures of automatic evaluations, are valuable tools (Wentura and Degner, 2010). This approach follows recommendations to move beyond sacrificial dilemmas when studying clinical variation in moral judgment (Rosas and Koenigs, 2014) by examining spontaneous reactions to moral transgressions. Second, in the current study we use formal modeling to quantify the latent component processes shaping moral judgments on the implicit measure. Applying formal modeling enhances theoretical precision and improves behavioral prediction (cf. Crockett, 2016). Here, we use a novel implicit measure of moral judgment and corresponding formal model to understand the nature of deficits in moral judgment among patients with vmPFC lesions.

In the current experiment, participants completed the Moral Categorization Task, a sequential priming task that involves making rapid moral judgments (Cameron et al., 2017). On each trial of this task, participants see two words in sequence (distracter and target), each of which is typically considered morally wrong (e.g., *genocide*) or morally neutral (e.g., *golf*). Participants are instructed to judge whether the target action is morally wrong or not while avoiding the influence of the distracter word, while under a response deadline to encourage speeded responding (Degner, 2009). Judgment accuracy is coded and compared across the distracter-target combinations in the task. Past research has documented within-subjects interference effects on moral judgments during this task. For example, when presented with morally wrong distracter actions such as *murder*, participants evince reduced judgment accuracy about morally neutral target actions (Cameron et al., 2017).

However, multiple processes might underlie this behavioral effect. To understand the underlying processes contributing to this performance bias on the Moral Categorization Task, we developed a multinomial model (Cameron et al., 2017) to formally quantify cognitive processes contributing to task performance (Riefer and Batchelder, 1988; Jacoby, 1991; Payne and Bishara, 2009; Bishara and Payne, 2009; Sherman et al., 2011). These models differ from traditional dual process models by making *a priori* formal assumptions about how component processes interact to produce task performance. These models do not make strong claims about dual systems (e.g., “System I” and “System II”), which have been criticized as a framework for understanding moral decision-making (Van Bavel et al., 2015). Given the set of assumptions posited by the model, task performance (i.e., judgment

accuracy on different trial types) can be used to estimate the probability of each underlying process operating. This approach allows us to formally quantify variation in our component process of interest—implicit moral evaluations—and isolate it from other processes influencing task performance (for discussion, see Payne and Cameron, 2014).

The multinomial model posits three processes driving judgment in the Moral Categorization Task: Intentional Judgment (I), Unintentional Judgment (U), and Response Bias (B). Performance bias on the Moral Categorization Task could be due to variation in any or all of these underlying processes, as explained below.

Intentional Judgment is the ability to follow task instructions and accurately judge target actions, which operates with probability I. Someone high in Intentional Judgment can successfully judge morality of target actions.

Unintentional Judgment is the evaluative tendency to morally judge target actions in a distracter-consistent manner, and operates when Intentional Judgment fails with conditional probability $(1 - I) \times U$. We stipulate that this process corresponds to implicit moral evaluations: someone high in Unintentional Judgment has stronger responses to distracter actions, which then influence judgments of target actions. Unintentional Judgment is distracter-consistent: if the distracter is morally wrong, then this should shift moral judgments of target actions toward “wrong”, and if the distracter is morally neutral, then this should shift moral judgments of target actions toward “not wrong.” Given that participants are instructed to ignore distracters, Unintentional Judgment is not merely spontaneous, but operates counter to participant intention.

Lastly, Response Bias is a directional tendency to always judge target actions as wrong with conditional probability $(1 - I) \times (1 - U) \times B$ or not wrong with $(1 - I) \times (1 - U) \times (1 - B)$. Someone high in Response Bias will judge target actions as wrong regardless of moral content.

Because performance can reflect contributions of each of these processes, formal modeling allows important precision in understanding variation in performance on the Moral Categorization Task. Increased performance bias in one group might be due to reduced Intentional Judgment of targets, increased Unintentional Judgment of distracters, or shifts in Response Bias. Clinical variation in moral judgment could be driven by distinct deficits in implicit moral evaluations and other processes, which the current approach can disentangle.

In multinomial modeling, the model is formally defined *a priori* using equations derived from the structure of the multinomial processing tree model (see Appendix for model equations). Using these equations and observed frequencies of accurate and inaccurate responses in each distracter-target combination of the task, parameter values are obtained with maximum likelihood estimation. The parameters represent the probability of each process operating to influence performance.

This task and model have been validated in previous research (Cameron et al., 2017). The Moral Categorization Task exhibits robust within-subject interference effects on moral judgment, and the underlying multinomial model fits the behavioral data. The process

parameters are influenced in expected ways by relevant manipulations. Imposing speeded response deadlines reduces Intentional Judgment, but not Unintentional Judgment or Response Bias, suggesting the former has operating conditions ascribed to controlled processes. As Unintentional Judgment is weaker in response to non-moral negative distracters (e.g., *cancer*), this parameter does not appear reducible to negative affect. The parameters exhibit convergent validity with moral personality: Unintentional Judgment after moral transgression distracters, but not after non-moral negative distracters associates positively with guilt proneness and moral identity, and negatively with self-reported psychopathy (Cameron et al., 2017).

In the current experiment, we expected that because lesions to the vmPFC disrupt affective processing, they should matter for situations in which affective processing plays a role, such as the Moral Categorization Task. To the degree that patients with vmPFC lesions have diminished responses to distracters (which rely upon affective processing), their target judgments should be less influenced by distracters compared to control participants. In other words, we expect that when seeing distracter actions that are normatively wrong, such as *murder*, patients with vmPFC lesions will show a weakened tendency to make spontaneous moral judgments about them, as revealed through their behavioral performance on the task.

Consistent with other neuroscientific approaches to morality (Decety and Cowell, 2014; Greene, 2015; Van Bavel et al., 2015; Young and Dungan, 2012), we do not sharply divide moral and non-moral cognition. We suggest that implicit moral evaluations involve not only negative affect, but also conceptual content about morality. Prior work indicates that the Unintentional Judgment parameter is stronger in response to morally wrong distracters (e.g., *murder*) than non-moral negative affective distracters (e.g., *cancer*; see Cameron et al., 2017). In other words, morally wrong distracters such as *murder* should have a stronger influence on moral judgments than non-moral negative distracters such as *cancer*. There is reason to believe that negative affect from non-moral distracters may play some causal role in shaping moral judgments (Haidt, 2001), but such an effect is likely to be strengthened when there is additional conceptual content grounding the affect in a moral norm and making it relevant for target judgments (Nichols, 2004). The vmPFC has been suggested to play a role in affective responses that are shaped by conceptual information (Roy et al., 2016). We expected that patients with vmPFC lesions would show reduced Unintentional Judgment toward both moral and non-moral negative distracters, given that both involve negative affect. However, we expected this deficit to be greater for morally wrong distracters, which would suggest that the vmPFC-related deficit in moral judgment involves knowledge about morality and is not reducible to negative affect alone.

2. Method

2.1. Participants

Patients were recruited from the Iowa Patient Registry, and informed consent was obtained. The patients, as is required for inclusion on the Patient Registry, have focal, stable lesions that are well-characterized through structural imaging (MRI scans for most patients and CT scans for those with conditions that preclude MRIs; Frank et al., 1997). Each patient on the registry has been screened by a neurologist and a neuropsychologist, excluding individuals

with a history of learning disabilities, psychiatric disorders, substance abuse, or other neurological conditions (Keifer and Tranel, 2013). All neuropsychological, neuroanatomical, and experimental data were collected at least three months after lesion onset, in the chronic epoch of recovery. We recruited individuals with lesions to the ventromedial PFC (vmPFC; $n = 8$; Table 1), a brain-damaged comparison group with lesions outside the vmPFC (BDC; $n = 7$),¹ and neurologically healthy comparisons (NL; $n = 16$). We excluded data for two healthy participants who switched key mappings, and one vmPFC participant and one healthy participant each who reported being unable to see the distracter stimuli. Table 1 lists demographic characteristics of the groups (not including an additional 9 BDC participants who were excluded in order to match on age, see footnote), and Table 2 lists lesion descriptions for the vmPFC and BDC groups.

Fig. 1 displays the lesion overlap map for all vmPFC patients.

2.2. Stimuli and tasks

2.2.1. Moral categorization task—Participants completed the experiment one at a time at a computer workstation. Participants were instructed:

Each trial of this task will start with a fixation cross, +, that you should keep your eyes on. Then we will show you pairs of words flashed one after the other. Ignore the yellow words, which come first. Blue words will come second. Your job is to make a quick judgment of whether the blue words represent an action that is morally wrong. If the blue word represents an action that is morally wrong, press the M key on the keyboard. If the blue word does not represent an action that is morally wrong, press the Z key. Ignore the influence of the yellow words that come beforehand. Finally, please respond as fast as possible.

Participants received 8 practice trials before the main trials began. Each trial began with a fixation cross displayed in the center of the screen for 200 ms. The cross was followed by a distracter word presented for 100 ms, a blank screen for 75 ms, and a target word which remained on screen until participants responded. If participants exceeded the 500 ms deadline, a message was displayed instructing them to respond faster. Participants completed two blocks containing 20 trials of each distracter-target combination, for a total of 360 test trials.

Distracter and target words were selected to represent actions typically considered morally wrong or neutral (as in Cameron et al., 2017). There were two lists of morally wrong words, two lists of non-moral negative words, and two lists of morally neutral words. The words in the two morally wrong word lists included: *murder, rape, abuse, theft, killing, assault, torture, betrayal, slaughter, and terrorism*. The words in the two non-moral negative word lists included: *distress, trauma, cancer, disaster, pain, accident, rejection, bankruptcy, rabies, and nightmare*. The words in the two morally neutral word lists included: *writing, golf,*

¹In addition to the 7 BDC patients analyzed in the current experiment, we recruited 9 additional BDC patients. These patients were younger, such that when including them in the sample there was a significant difference in age across the patient groups, $F(2, 37) = 12.06, p < .001$, with the BDC group younger ($M = 52.75, SD = 13.76$) than the vmPFC group and neurologically healthy group, ($ps = .001$). In order to ensure that demographics were matched across patient groups, we excluded BDC patients younger than 55 years of age in the analyses reported in the main text.

baking, agreement, leisure, painting, tennis, farming, modesty, and exercise. Although it is possible that some people might construe words in the non-moral stimulus categories as morally relevant, we believe that this is less likely to occur on average compared to words in the morally wrong lists. Distracter-target pairs were presented randomly and word lists were counterbalanced. Separate from this primary task, participants also completed exploratory individual difference measures which are not discussed further (guilt and shame proneness: Cohen et al., 2011; self-reported psychopathic tendencies: Levenson et al., 1995; sacred value judgments: Graham et al., 2009).

2.3. Data analysis

We first determined whether there was a difference in performance on the Moral Categorization Task between the brain-damaged control and neurologically healthy groups, using a 2(Group: BDC, NL) $\times$ 3(Distracter: Wrong, Negative, Neutral) $\times$ 2(Target: Wrong, Neutral) mixed ANOVA. For wrong-target trials, we coded “wrong” judgments as accurate and “not wrong” judgments as inaccurate. For neutral-target trials, we coded “not wrong” judgments as accurate and “wrong” judgments as inaccurate. We excluded negative-target trials from analysis given prior findings that these are often judged more inaccurately and compromise model fit (Cameron et al., 2017). Replicating prior work (Cameron et al., 2017), a Distracter $\times$ Target interaction emerged, $F(2, 36) = 5.22$, $p = .010$, $\eta_p^2 = .23$, which was not moderated by Group, $F(2, 36) = 2.67$, $p = .083$, $\eta_p^2 = .13$. Given that the critical interaction did not differ between BDC and NL groups, we combined them into a single comparison group to increase statistical power (cf. Thomas et al., 2011).

3. Results

3.1. Error rates

We determined whether there was a difference in performance across groups on the Moral Categorization Task, using a 2(Group: vmPFC, Comparison) $\times$ 3(Distracter: Wrong, Negative, Neutral) $\times$ 2(Target: Wrong, Neutral) mixed ANOVA. There was not a Distracter $\times$ Target interaction, $F(2, 50) = 1.39$, $p = .258$, $\eta_p^2 = .05$, or Distracter $\times$ Target $\times$ Group interaction, $F(2, 50) = 2.16$, $p = .126$, $\eta_p^2 = .08$. Table 3 displays error rates by group (splitting into all three groups for descriptive purposes), distracter, and target. Although the results did not reveal behavioral differences in error rates across groups, differences in underlying process parameters can still exist as modeling allows the decomposition of such differences in a manner that cannot be obtained from behavioral results alone. Data and analysis syntax for the error rates and multinomial model are located on the Open Science Framework.

3.2. Multinomial model

We conducted multinomial modeling analyses using the software program MultiTree (Moshagen, 2010). Parameters are estimated through maximum likelihood estimation, based upon the observed frequencies of accurate and inaccurate responses in each cell, and using model equations derived from the processing tree model (see Appendix for equations). Model fit is assessed with a likelihood-ratio G^2 statistic, with model fit indicated by non-significant G^2 . If constraining a parameter across participant groups significantly reduces

model fit, then the groups differ in the underlying process. Effect sizes are derived for these comparisons using effect size w . For each group, we estimated one Intentional Judgment parameter, two Unintentional Judgment parameters (for wrong and negative distracters, with Unintentional Judgment toward neutral distracters set to zero as in Cameron et al., 2017), and one Response Bias parameter, and excluded negative-target trials (as in Cameron et al., 2017). Model fit was adequate, $G^2(4)=8.68$, $p=.070$, $w=.04$. Table 4 displays parameter estimates for each of the groups.

As seen in Table 4, the vmPFC group was lower than the comparison group in Intentional Judgment, $G^2(1) = 225.72$, $p < .001$, $w = .19$, and in Unintentional Judgment after wrong distracters, $G^2(1) = 6.79$, $p = .009$, $w = .03$, but not in Unintentional Judgment after negative distracters, $G^2(1) = 2.08$, $p = .149$, $w = .02$. Compared to the vmPFC group, the comparison group was more likely to exhibit a Response Bias to always judge target actions as not morally wrong, $G^2(1) = 12.09$, $p < .001$, $w = .04$. Thus, compared to patients with non-vmPFC brain damage and neurologically healthy participants, patients with vmPFC lesions were less able to make accurate moral judgments about target actions, suggesting reduced intentional moral judgment, and showed impaired unintentional moral judgments specifically in response to morally wrong distracters, but not in response to non-moral negative distracters. According to effect size conventions (Cohen, 1988), the Intentional Empathy effect should be considered small-to-medium, whereas the others should be considered small. Although the study was sufficiently powered to detect the Intentional Judgment group difference, the Unintentional Judgment comparisons were underpowered and should be followed up with additional studies that either increase the sample size or number of trials in the Moral Categorization Task.

4. Discussion

The current experiment used a novel implicit measure and multi-nomial modeling approach to examine the role of the ventromedial prefrontal cortex in moral judgment. In the Moral Categorization Task, participants made moral judgments about target actions while attempting to avoid the influence of distracter actions. Although there was a within-subjects interference effect on moral judgment among the contrast groups, consistent with previous uses of this task (Cameron et al., 2017), it did not differ between patients with vmPFC lesions and participants without vmPFC damage (BDC and NL). Using multinomial modeling, we successfully decomposed task performance into three processes: Intentional Judgment (ability to make accurate moral judgments about target actions), Unintentional Judgment (an evaluative tendency to judge the morality of target actions in a distracter-consistent way), and Response Bias (directional tendency to always judge target actions as either “wrong” or “not wrong”).

Patients with vmPFC damage showed differences from comparisons in underlying processes estimated by the multinomial model. As expected, patients with vmPFC lesions experienced reduced Unintentional Judgments in response to moral transgression distracters. In other words, patients with vmPFC damage had weaker implicit moral evaluations of moral transgressions. This effect was specific to moral content and did not reflect a domain-general affective deficit, as Unintentional Judgment did not differ between patient groups in

response to non-moral negative affective distracters that had been matched on valence and arousal. Patients with vmPFC damage also exhibited reduced Intentional Judgment relative to controls, indicating decreased ability to follow task instructions and make intentional moral judgments about target actions. To date, this is the first research to use implicit measurement and multinomial modeling to examine moral judgments in patients with vmPFC lesions. The dual deficits in intentional and unintentional moral judgment indicate the value of a formal modeling approach: not only do patients with vmPFC lesions have reduced implicit moral evaluations in response to distracters, but they also exhibit reduced ability to intentionally morally judge targets.

These results are consistent with previous research documenting differences in moral judgment and moral behavior among patients with vmPFC lesions. These patients are generally less affectively responsive to social stimuli (Damasio et al., 1990), have difficulties incorporating affect into decision-making (Bechara et al., 1996), and exhibit abnormal social and moral behavior despite having intact reasoning and social knowledge (Anderson et al., 1999; Eslinger and Damasio, 1985; Eslinger et al., 2004; Saver and Damasio, 1991). Patients with vmPFC lesions are more likely to make utilitarian decisions in high-conflict dilemmas involving tradeoffs between deontological rules and utilitarian outcomes (Koenigs et al., 2007; Ciaramelli et al., 2007; Thomas et al., 2011). This pattern is thought to result from patients with vmPFC lesions lacking affective responses to harming the single victim in these dilemmas (Thomas et al., 2011), and could reflect difficulties integrating affect into decision-making (Shenhav and Greene, 2014).

Aside from differences in Unintentional Judgment, patients with vmPFC damage also showed reduced Intentional Judgment, meaning they were less able to follow task instructions and make accurate moral judgments about target actions. This finding is consistent with prior research that implicates vmPFC deficits in lower impulse control (Boes et al., 2008). Intentional Judgment has previously been found to exhibit characteristics of controlled processing: it is reduced when imposing speeded response deadlines, and converges with the error-related negativity, a neurophysiological signal for behavioral control (Cameron et al., 2017). Another explanation of this result is that target judgments on the Moral Categorization Task require integration of emotion into moral judgment. Emotion integration deficits among patients with vmPFC lesions may influence both unintentional and intentional moral judgment.

Finally, there were differences across groups in Response Bias: the comparison group had a stronger bias toward judging all targets as not morally wrong, regardless of context, compared to the vmPFC group. The Response Bias parameter represents a conditional probability, contingent on Intentional Judgment and Unintentional Judgment failing to operate. For this reason, the bias is less theoretically interesting and is only included as a means of dissociating distracter-consistent evaluative responding (Unintentional) from generalized response biases that do not take stimulus content into account. Second, one possible interpretation is that in the absence of making a moral judgment about the target (Intentional) or about the distracter (Unintentional), patients with vmPFC lesions are more likely to judge everything as wrong to appease the experimenter. Although the population is not identical, some prior work finds that clinically diagnosed psychopathic individuals fail to

make the moral-conventional distinction, and the pattern is such that they judge *all* violations, be they moral or conventional, as moral violations (Blair, 1995).

Future experiments should extend the Moral Categorization Task and multinomial model to other clinical populations. Contrary to patients with adult-onset vmPFC lesions, patients with early-onset vmPFC lesions are more likely to endorse harmful actions even without utilitarian justification (Taber-Thomas et al., 2014), and to show broader deficits in social and moral reasoning (Anderson et al., 1999, 2000). One possible explanation is that early damage to the vmPFC impairs the acquisition of moral knowledge (Taber-Thomas et al., 2014). If so, we would predict that patients with early-onset vmPFC damage would show even greater reductions in Unintentional Judgment toward moral transgressions. This approach can also be used to study criminal psychopaths, whose tendencies to engage in callous and impulsive behaviors have also been linked with differences in the vmPFC (Blair, 2007). Although some research has used implicit measures to capture moral evaluations by psychopaths (e.g., Gray et al., 2003), no research has used multinomial modeling to quantify underlying processes and isolate effects specific to moral evaluations.

In summary, the current experiment used indirect measurement and multinomial modeling to reveal a multi-faceted deficit in moral judgment for patients with vmPFC lesions. Patients with vmPFC lesions showed reduced implicit moral evaluations of harmful moral transgressions, and also a reduced ability to make intentionally controlled moral judgments about actions. By capturing the kinds of implicit moral evaluations that we may often have in response to transgressions that we witness or read about in everyday life, the current measure can increase the impact of moral neuroscience research in clinical populations and increase understanding of variation in everyday moral behavior.

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Appendix

Multinomial model equations

$$p(\text{accurate}|\text{wrong distracter}\&\text{wrong target})=I+(1-I)\times U+(1-I)\times(1-U)\times B$$

$$p(\text{inaccurate}|\text{wrong distracter}\&\text{wrong target})=(1-I)\times(1-U)\times(1-B)$$

$$p(\text{accurate}|\text{wrong distracter}\&\text{neutral target})=I+(1-I)\times(1-U)\times(1-B)$$

$$p(\text{inaccurate}|\text{wrong distracter}\&\text{neutral target})=(1-I)\times U+(1-I)\times(1-U)\times B$$

$$p(\text{accurate}|\text{neutral distracter}\&\text{wrong target})=I+(1-I)\times(1-U)\times B$$

$$p(\text{inaccurate}|\text{neutral distracter}\&\text{wrong target})=(1-I)\times U+(1-I)\times(1-U)\times(1-B)$$

$$p(\text{accurate}|\text{neutral distracter}\&\text{neutral target})=I+(1-I)\times U+(1-I)\times(1-U)\times(1-B)$$

$$p(\text{inaccurate}|\text{neutral distracter}\&\text{neutral target})=(1-I)\times(1-U)\times B$$

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Fig. 1.

Lesion overlap of patients with vmPFC damage. Lesions from all 8 patients are displayed in (A) mesial, frontal, and lateral views and (B) horizontal slices. Colors represent the number of overlapping lesions at each voxel, with a maximum of 7 in (A) and 8 in (B). The lesions of all eight patients in the vmPFC group overlapped primarily in the vmPFC.

Table 1

Demographic characteristics of patient groups.

ID	Sex	Age	Education	Aetiology ^a
0318	M	75 y	14	Resection
2112	M	61 y	18	Trauma
2391	F	69 y	13	Resection
2855	M	68 y	12	Resection
3534	F	76 y	12	Resection
3535	F	69 y	16	Resection
3591	F	72 y	12	Trauma
3652	F	66 y	13	Resection
vmPFC M (SD)	5F/3M	69.50 (4.87)	13.75 (2.19)	
Brain-damaged comparison, M (SD)	4F/3M	65.43 (6.90)	15.71 (3.73)	
Neurologically healthy, M (SD)	10F/6M	66.50 (4.20)	15.73 (2.52)	

^a Resection denotes surgical resection of a benign tumor (meningioma); trauma denotes focal contusion with localized parenchymal damage.

Table 2

Lesion descriptions for patients with lesions to the ventromedial prefrontal cortex (vmPFC) and brain-damaged comparison patients (BDC).

Patient ID	Group	Lesion description
2246	BDC	L temporal lobectomy (epilepsy resection)
2328	BDC	R middle cerebral artery infarct (stroke)
2403	BDC	L temporal lobectomy (epilepsy resection)
2527	BDC	L frontal infarct (stroke)
3124	BDC	L subdural hematoma (resection)
3543	BDC	L insular infarct (stroke)
3575	BDC	Bilateral occipital infarcts (stroke)
0318	vmPFC	Bilateral frontal meningioma resection (benign tumor resection)
2112	vmPFC	L frontal hemorrhagic stroke (stroke + resection)
2391	vmPFC	Bilateral frontal meningioma resection (benign tumor resection)
2855	vmPFC	Bilateral frontal meningioma resection (benign tumor resection)
3534	vmPFC	Bilateral frontal olfactory groove meningioma resection (benign tumor resection)
3535	vmPFC	R frontal meningioma resection (benign tumor resection)
3591	vmPFC	Subarachnoid hemorrhage with bifrontal contusions (focal trauma)
3652	vmPFC	Bilateral frontal olfactory groove meningioma resection (benign tumor resection)

Table 3

Mean (SD) Proportion of errors by participant group, distracter type, and target type.

Group/Target	Wrong distracter	Negative distracter	Neutral distracter
vmPFC			
Wrong target	.20 (.25)	.24 (.27)	.21 (.23)
Neutral target	.15 (.18)	.19 (.18)	.17 (.20)
BDC			
Wrong target	.03 (.02)	.05 (.05)	.04 (.05)
Neutral target	.09 (.19)	.09 (.18)	.08 (.18)
NL			
Wrong target	.07 (.06)	.08 (.08)	.15 (.11)
Neutral target	.03 (.04)	.02 (.03)	.01 (.02)

Table 4

Parameter estimates by participant group and distracter type.

Group/Parameter	Wrong distracter Estimate [95% CI]	Negative distracter Estimate [95% CI]	Neutral distracter Estimate [95% CI]
vmPFC			
Intentional	.61 [.58, .65]	–	–
Unintentional	.00 [–.21, .21]	.01 [–.20, .21]	.00 (constant)
Response Bias	.43 [.35, .52]	–	–
Comparison			
Intentional	.88 [.87, .89]	–	–
Unintentional	.31 [.16, .46]	.18 [.03, .33]	.00 (constant)
Response Bias	.23 [.16, .31]	–	–

Note. Intentional Judgment and Response Bias parameters constrained to be equal across distracter conditions, and Unintentional Judgment constrained to zero in the Neutral condition.