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What is the role of ventromedial prefrontal cortex in emotional influences on reason?

Antoinette Nicolle and Vinod Goel

Summary

This chapter reviews evidence for the role of the ventromedial prefrontal cortex (vmPFC) in emotional influences on reasoning and decision-making. Theoretical accounts of this role are discussed and it is debated whether these can be convincingly supported by the data. Finally, some challenges faced for future research into the neural basis of emotion–reason interactions are considered.

Introduction

Aristotle defined man as the rational animal. This pertains to the fact that our thoughts and actions are said to be guided by reason. Reason requires that we have beliefs and desires, and that we pursue the latter in the context of the former. That is to say, our behaviour can be considered rational when our actions are consistent with achieving our goals, in the context of our knowledge or beliefs.

For example, if we are thirsty and desire to drink water, and if we believe that water can be obtained by walking 50 yards southeast, and we proceed to do so, then we are behaving rationally. But if we proceed to walk 50 yards north, then, in the absence of any other superseding goals, we are being irrational. In this way, rationality provides a causal explanation for much of our behaviour.

Like beliefs and desires, emotions are also intentional states. That is, they are referential, or directed. For example, if one is afraid of spiders, then this fear is directed at spiders. Importantly, emotions are also characterized by a qualitative feeling associated with physiological arousal, which focuses attention and prepares the body for action, and a valence (pleasure-pain) metric, which allows for arousal to mobilize behaviour in a direction appropriate for the pursuit of one's desire. As rationality is considered to be causally efficacious in our behaviour, so are emotions. We strike out when angry, hide when afraid, and cry when sad. Emotions, like beliefs and desires, also influence the way we appraise our environment. For example, a spider phobic may be hypervigilant and avoidant of situations in which spiders may be encountered. Similarly, a happy person may notice the sun shining or the colour of the trees more so than would a sad person.

Western European society has always valued behaviour motivated by rationality above behaviour motivated by 'passion'. Of course, man is neither purely rational nor purely emotional. Our thoughts and actions arise from the interaction of the rational and emotional minds. For example, in reviewing a high quality article disproving a theory he has worked on for years, the scrupulous editor of a psychology journal faces a conflict between reason and his defensive emotional response. The historical view of this interaction is based on the assumption that the rational mind is best qualified to guide behaviour, and that the emotional mind must be kept in check since it would only pollute the process (Seneca, 1928).

In recent years, however, emotions have been given a 'second chance' (Damasio, 2000), as more and more evidence suggests that emotions are often, though not always, beneficial to reason.

This second chance, and the growing interest in emotion-reason interactions in the field of neuroscience, owe much to the work of Antonio Damasio and colleagues. Their observations of patients with brain damage have exposed the apparent 'limits of pure reason' when normal emotional responding is disrupted. They describe a patient who, when attempting to choose between two dates for his next doctor's appointment, becomes lost in a vigilant, but ultimately hopeless, cost-benefit analysis (Damasio, 1994). Since neither date is deemed to be superior from this analysis, the patient is unable to reach a decision. Damasio suggests that an apparent lack of normal emotional influences on reason has prevented the patient from reaching a decision based on any kind of emotional intuition or gut feeling.

Damasio's observations hint that emotions continuously influence, for better or for worse, our capacity for reason. Certain types of brain damage result in an intriguing comorbidity of emotional disruption and impaired reasoning, particularly in complex real-world and social scenarios. Despite the importance of emotions in understanding behaviour, cognitive psychology and cognitive neuroscience have, in the past, had relatively little to say about them. This neglect is perhaps because it has been difficult to reach an agreed-upon definition of what emotions actually are. Moreover, the computational story of mind is well suited to deal with the intentionality of mental states but not with the affective constructs of arousal or valence. However, since its 'second chance' in the clinical and cognitive neurosciences, the evidence seems to be pointing more and more towards a central role of ventral and medial regions of the prefrontal cortex (vmPFC) in emotional influences on reasoning and decision-making.

This work has tended to span three literatures: (1) formal reasoning; (2) preference-driven decision-making; and (3) moral reasoning. Logical reasoning is the process of drawing inferences from available information in accordance with normative rules. Preference-driven decision-making research explores how people value, and choose between, prospects under conditions of uncertainty. While some of the judgements necessary for decision-making may be comparable to those used in

some forms of reasoning (e.g., probability judgements or the influence of belief), the decision-making literature places far greater emphasis on anticipated reward and punishment than does the reasoning literature. In our heavily social world, studies of moral reasoning attempt to understand how we judge the appropriateness of our actions, beliefs and preferences, and those of others, in a socially interactive context. On occasion, these three literatures can appear quite disconnected, and yet each is associated with understanding the pursuit of rationality in a complex and uncertain world. This chapter will explore some key studies of the neural basis of emotional influences on reason from each of these literatures, and consider the extent to which they support a critical role of vmPFC in such influences.

Neuroanatomical basis of emotion in reasoning

The curious case of Phineas Gage

In 1848, a 25-year-old man, Phineas Gage, sustained severe damage to the frontal lobes of his brain when an explosion drove an iron rod through his skull (Harlow, 1848). Amazingly, Gage survived, though in a seemingly altered state. Harlow later described the profound changes in Gage's personality since the accident (Harlow, 1868), with a particular emphasis on his apparent lack of emotional intelligence and restraint. He wrote that the 'equilibrium or balance, so to speak, between his intellectual faculties and his animal propensities, seems to have been destroyed'. To his friends and family, Gage was sadly 'no longer Gage'. While an autopsy was never performed on Gage, subsequent work has reconstructed the most plausible location of brain damage based on computer simulation and meticulous analysis of Gage's recovered skull. This work has confined the damage to prefrontal cortex, most extensively in the left hemisphere, and more markedly in ventral and medial portions than in the dorsal and lateral portions (Damasio, Grabowski, Frank, Galaburda, & Damasio, 1994).

Structure and function of vmPFC

As a whole, the prefrontal cortex is commonly implicated in reasoning and decision-making, especially under conditions of uncertainty or novelty. Ventromedial regions of the prefrontal cortex (vmPFC) are thought to be particularly involved in the use of goal-relevant information in guiding responses, e.g., assigning value to choice options. Here we use the term ventromedial prefrontal cortex (vmPFC) to encompass, bilaterally, the medial portions of orbitofrontal cortex as well as ventral portions of the medial surface of the prefrontal cortex (PFC), while excluding lateral portions of the orbitofrontal cortex and the more dorsal and posterior portions of medial PFC. While the precise boundaries of vmPFC are not always agreed upon, this broad definition in the human brain (illustrated in Figure 9.1(a)) is well accepted (Mackey & Petrides, 2010; Mitchell, 2011; Öngür, Ferry, & Price, 2003). In contrast, dorsolateral prefrontal cortex (dlPFC), encompassing an anatomically distinct region of PFC (illustrated in Figure 9.1(b)), is more commonly involved in various 'executive' cognitive tasks and inhibition.

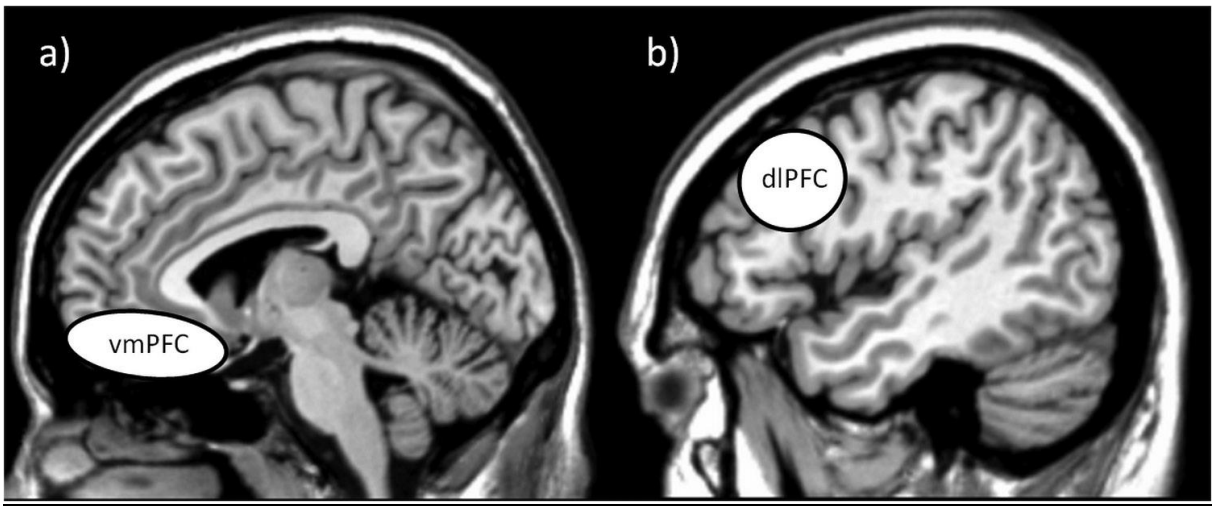

Figure 9.1 (a) Illustrated location of human vmPFC, shown on a sagittal section through the midline of the brain. vmPFC usually includes Brodmann areas 25, medial portions of 11 and 12, and the most ventral and medial portions of 10 and 32. The human analogue of primate areas 13 and 14 are also commonly included. (b) Illustrated location of human dlPFC, shown on a lateral sagittal section of the brain, usually considered to encompass Brodmann areas 9/46.

The anatomical connectivity of vmPFC makes it well suited for a central role in both emotion and reasoning. It receives highly processed sensory information from association cortices, such that it is well informed about the current external and internal environment. It is also well connected to the amygdala, cingulate, insula, inferior parietal cortex and striatum, all commonly implicated in emotional experiences and their behavioural effects. Moreover, it projects to limbic structures, thalamus, hypothalamus and brain stem which are integral to executing visceral responses in the body, as well as neurochemical changes in the brain. The vmPFC is also significantly connected to dlPFC and, as we shall see later in this chapter, these connections may be of particular importance for emotion–reason interactions.

Emotion in Decision-Making implicates vmPFC

While the story of Phineas Gage may be dramatic, it was not particularly well documented. Empirical tests of Gage's precise abilities and deficits were not performed. Moreover, the brain damage included some dorsal regions of PFC, and *in vivo* analyses of the precise brain damage were not conducted. Even the description of Gage's behavioural change has since been called into question (Macmillan, 2002).

In recent years, other cases of vmPFC-damaged patients have been documented, and extensive behavioural testing and brain imaging have allowed their descriptions to be more precise. Elliot was such a patient, having suffered focal vmPFC damage after the removal of a brain tumour from just above the eyes (Damasio, 1994). After surgery, Elliot showed no clear deficit in normal measures of IQ, attention, working memory, language or social knowledge. However, like Gage, 'Elliot was no longer Elliot' and his planning and real-world decision-making had become extremely impaired. Like Gage, this reasoning deficit ran alongside muted emotional processing such that even

Elliot himself could ‘sense how topics that once had evoked a strong emotion no longer caused any reaction, positive or negative’.

From their observations of Elliot, and other similar patients, Damasio and colleagues questioned why such covariation would exist between defective emotional responses and impaired reasoning. In stark contrast to traditional views, they concluded that, when it comes to everyday reasoning (but not laboratory measures of IQ), ‘well-tuned and deployed emotion … is necessary for the edifice of reason to operate properly’ (Damasio, 2000).

Much of the original support for this claim was provided by testing vmPFC-damaged patients on the Iowa gambling task (IGT) (Bechara, Damasio, Damasio, & Anderson, 1994). In this task, participants must learn which out of four card decks are most advantageous. Two of the four decks are ‘risky’, providing large monetary rewards early in the game but even greater losses over time. The remaining two decks are ‘safer’, and provide an overall profit over time, although with smaller rewards and smaller losses. Therefore, while the risky decks are tempting at first, the individual must learn to favour the safer decks in order to win money in the task. While healthy individuals can learn to avoid the risky decks, vmPFC-damaged patients were consistently impaired on the IGT, seemingly being unable to avoid the risky decks (Bechara et al., 1994). Moreover, while healthy controls typically exhibit anticipatory physiological responses in the IGT (in the form of skin conductance changes prior to choice), vmPFC-damaged patients showed no such anticipatory responding (Bechara, Tranel, Damasio, & Damasio, 1996). vmPFC activity has been implicated in the generation of skin conductance responses (SCRs) in healthy individuals (e.g., Critchley, Corfield, Chandler, Mathias, & Dolan, 2000), implying that vmPFC damage would impair such responses and that this could explain impaired decision-making in the task (see Chapter 7 of this volume).

Some psychiatric conditions with possible links to vmPFC abnormality have also been associated with poor performance in the IGT. For example, substance-dependent individuals behave

in a similar way to vmPFC-damaged patients in the IGT (Bechara & Martin, 2004), an effect which may be associated with reduced grey matter density in their vmPFC (Tanabe et al., 2009). Moreover, recent neuroimaging studies on healthy individuals have also shown that vmPFC activity is recruited when playing the IGT (e.g., Lawrence, Jollant, O'Daly, Zelaya, & Phillips, 2009; Li, Lu, D'Argembeau, Ng, & Bechara, 2010).

These observations have led many neuropsychologists to suggest that the vmPFC plays a special role in emotional influences on preference-driven decision-making. Despite the close relationship between reasoning and decision-making, indeed, Damasio wrote that 'it is perhaps accurate to say that the purpose of reasoning is deciding' (Damasio, 1994), only a modest few studies have addressed emotional influences on formal reasoning from a neuroscience perspective. Nonetheless, while theoretical models of emotional influences on reasoning are still in their infancy, the growing number of relevant behavioural studies (seen throughout this volume) provide a modest, but respectable, foundation for future neuroscientific exploration. As in the case of preference-driven decision-making, we shall see below that the small amount of work in the domain of formal reasoning also appears to support a critical role of vmPFC in emotional influences.

Emotional Content in Logical Reasoning implicates vmPFC

To explore the neural basis of emotional influences on logical reasoning, Goel and Dolan (2003a) compared neuronal responses in healthy individuals while they performed a deductive reasoning task with and without emotional content. The task required participants to judge the logical validity of emotionally salient (negatively valenced and highly arousing) or emotionally neutral syllogisms (see Figure 9.2). For example, participants judged the logical validity of the emotionally salient syllogism: 'All murderous people are criminals. All Nazis were murderous. ∴ Some Nazis are criminals', or the emotionally neutral syllogism: 'No fruits are fungi. All mushrooms are fungi. ∴ Some mushrooms are fruits.'

	Emotional Content	Neutral Content
Reasoning	Some wars are not unjustified. All wars involve raping of women. Some raping of women is not unjustified.	Some Canadians are not children All Canadians are people Some people are not children
Baseline	Some wars are not unjustified. All wars involve raping of women. Some Indians are dishonest.	Some Canadians are not children All Canadians are people Some babies are curious.

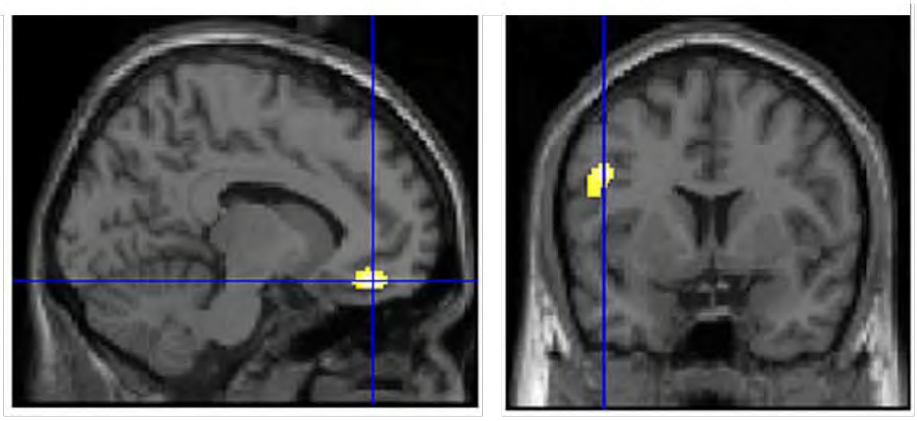

Figure 9.2 Enhanced neuronal response to emotional reasoning (minus emotional baseline) is evident in bilateral vmPFC, while enhanced response to neutral reasoning (minus neutral baseline) is found in left dlPFC.

Source: Reproduced with permission from Goel & Dolan (2003a), © Neuroimage.

To identify responses associated with emotional reasoning, rather than with a direct effect of the emotional content itself, Goel and Dolan included a baseline condition (for both the emotional and neutral syllogisms), where the conclusion was irrelevant to the previous two premises, such that no reasoning was necessary to judge the conclusion as invalid.

While no behavioural differences were found between emotional and neutral trials, in terms of reasoning accuracy or response times, brain responses to reasoning (relative to baseline) were different depending on whether the content was emotionally salient or neutral. Reasoning about emotionally neutral syllogisms (relative to the neutral baseline) was associated with blood oxygenation changes in left dlPFC, while reasoning about emotionally salient syllogisms (relative to the emotional baseline) was associated with changes in vmPFC responding. Moreover, both of these

responses were modulated as a function of participants' subsequent ratings of the emotional saliency of the trial. These effects were such that vmPFC responses to emotional reasoning were stronger when the content was rated as more emotionally salient, and dlPFC responses to neutral reasoning were stronger when the content was rated as less emotionally salient. From these findings, the authors argued for the presence of one reasoning system, modulated by reciprocal activation in dlPFC and vmPFC as a function of emotional saliency.

Goel and colleagues also tested this task on patients with focal brain damage. If the influence of emotion on logical reasoning is similar to that of emotion on preference-based decision-making, then one would predict that vmPFC-damaged patients would show a specific deficit in logical reasoning with emotional content. Moreover, by testing such patients, Goel, Lam, Raymont, Krueger, and Grafman (in preparation) were able to test whether vmPFC is *necessary* for emotional deductive reasoning, rather than just *associated* with the processes involved (as shown from the functional imaging findings). From this work, Goel et al. found that intact vmPFC is necessary for normal reasoning with emotional content. Specifically, they found that patients with focal lesions to vmPFC were impaired only when reasoning about emotionally salient content (relative to both non-brain-damaged controls and to patients with damage to parietal cortex). In contrast, these vmPFC patients were not impaired when reasoning about emotionally neutral content.

Interestingly, the deficit shown by these patients was confined to trials in which the correct (i.e., logical) answer was incongruent with participants' beliefs about the conclusion (e.g., the logically invalid but believable syllogism, 'No Americans are evil. Some serial killers are Americans. ∴ All serial killers are evil'). In contrast, the patients were not impaired when beliefs and logic were congruent (e.g., the valid and believable syllogism, 'No little girls die of AIDS. Some children are little girls. ∴ Some children do not die of AIDS'). These findings hint that the importance of vmPFC in emotional reasoning may be mediated by an influence of prior beliefs on reasoning. That the patients showed no difference from controls in terms of the strength of their

beliefs about the conclusions, suggests that it was not the beliefs themselves that were affected by vmPFC damage, but rather the ability to *use* these beliefs in reasoning.

A small amount of work has tried to make closer links between the motivations important in the preference-based decision literature, and the formal rules assumed to govern behaviour in logical reasoning studies. For example, some studies have varied the relevance of emotional content in logical reasoning tasks for the particular reasoner, and early findings show that people can reason more accurately about emotional contents when the contents are personally relevant (Blanchette & Campbell, 2012; Blanchette, Richards, Melnyk, & Lavda, 2007). Westen et al. (2006) show vmPFC involvement in a form of 'motivated reasoning', in which participants reasoned about information that was threatening to their preferred political party. In a study by Houdé et al. (2001), vmPFC activity was also found to be enhanced by a highly emotional form of training on a rule falsification task (though note that this activity may have been associated with residual emotional responding from the training or with improved task performance, and so it is yet unclear the extent to which vmPFC activity reflected emotional influences on reasoning). Such work, which attempts to bridge an individual's preferences and practical goals with the epistemic goals of formal reasoning tasks, may provide a necessary bridge between the two streams of literature.

Emotion in Moral Judgement implicates vmPFC

In our social world, reasoning often involves judgements of the moral nature of our behaviours, beliefs and preferences, and those of others around us. As a result, a third stream of literature exploring the neural basis of emotion–reason interactions has come from moral psychology. Moral judgement may provide a convenient link between work on formal reasoning, which deals mostly with normative rules, and preference-driven decision-making, which deals with the pursuit of rewards and the avoidance of punishment. In moral dilemmas, our judgements can

often be influenced both by our understanding of social and moral norms, as well as our own personal motivations.

Social and moral judgements are also often of a strongly emotional nature. Decisions to donate to a children's charity may be associated with sadness and guilt. Protests against our government's policies are commonly linked to disgust and anger. David Hume viewed moral judgements as arising purely from 'sentiment', rather than from rationality, and others since have argued that, more often than not, moral judgements stem from our affective reactions to the behaviours of others (Haidt, 2001).

Compared to the logical reasoning domain, there has been significantly more work exploring the neural basis of (apparently) emotional influences in moral judgement. The types of tasks used in studies of moral reasoning are quite different from those used in both the formal reasoning and preference-driven decision literature, and yet the results from this literature commonly also implicate the vmPFC.

In the Trolley Dilemma (Thomson, 1986), participants are asked to imagine that a runaway trolley is heading towards five people, who will be killed if the trolley continues on its course. The participant must choose between two response options. Would they turn a switch to send the trolley along a different course, where only one person would be killed, or would they choose not to intervene? Most people would choose to turn the switch, and judge this as the more moral option. In variations of this dilemma, the response options are changed. Would the participant be prepared to push someone in front of the trolley to stop it in its tracks? In this dilemma (coined the Footbridge Dilemma), the more personal nature of pushing someone onto the tracks tends to discourage such response, despite the outcome (of one person's death) being identical to that of turning the switch in the original Trolley Dilemma. Greene et al. (2001) found increased activity in a network of brain regions typically associated with emotion, including vmPFC, in more personal moral reasoning (as in

the Footbridge Dilemma) compared to impersonal moral reasoning (as in the Trolley Dilemma) and compared to non-moral reasoning. They proposed a critical role of emotion in the difference between personal and impersonal moral reasoning. In a discussion of these findings, Greene (2005) argued that, when the scenario is more personal, we respond in a more emotional fashion and these responses have a critical influence on our judgements and actions. As in both the logical reasoning and the preference-driven decision-making literature, vmPFC involvement in moral reasoning has also been implicated through observations that vmPFC-damaged patients make unusually utilitarian moral judgements (Ciaramelli, Muccioli, Làdavas, & Di Pellegrino, 2007), especially in cases of high conflict personal moral judgements (Koenigs et al., 2007).

Unfortunately, Greene et al. did not provide measures of emotional responding in their task to support their conclusion. It seems likely that a personal involvement is *necessary* for strong emotional responses to be induced by moral dilemmas. However, personal involvement is unlikely to be *sufficient* for an emotional response. Consequently, Greene et al.'s findings of differential brain responses to personal and impersonal moral reasoning may not require an appeal to emotion, but may be explicable through a purely cognitive account, e.g., higher cognitive conflict or greater reliance on theory of mind. It is not enough to assume that emotional processes must be involved because typically 'emotional' brain structures are found to be active. At this point, more explicit manipulations, and measurements, of emotion were needed in the moral reasoning literature, as was typical of the logical reasoning studies and preference-driven decision-making studies described above.

Moll and colleagues conducted a series of experiments that more explicitly addressed the neural basis of 'emotional' moral judgement. In contrast to Greene et al. (2001), these experiments varied the emotionality of the content and also measured participants' emotional responses through subjective ratings. In one experiment, participants were asked to covertly judge written statements as either morally 'right' or 'wrong', while their brain responses were imaged. After scanning, they also

provided ratings of the degree of moral content and valence of each statement (Moll, de Oliveira-Souza, Bramati, & Grafman, 2002). Moll et al. compared responses to emotionally negative moral (e.g., 'He shot the victim to death'), emotionally negative non-moral (e.g., 'He licked the dirty toilet'), and non-moral emotionally neutral statements (e.g., 'He never uses the seat belt'). They found that moral emotional content was associated with more negative valence than non-moral emotional content, though both were significantly more negatively valenced than the neutral content. In a second experiment, this time using pictures, moral negative pictures were actually rated as less unpleasant and less arousing than non-moral negative pictures, although both were more unpleasant and more arousing than control pictures (Moll, de Oliveira-Souza, Eslinger, et al., 2002). Despite these differences in affective ratings, *both* experiments found greater vmPFC activity for the moral emotional than for the non-moral emotional stimuli.

While this moral reasoning work parallels both the logical reasoning and the preference-driven decision-making domain in terms of implicating vmPFC, it is yet unclear what precisely this role of vmPFC is. It would be incorrect to blindly assume that the common involvement of vmPFC is driven entirely by emotional influences. In particular, there is not yet adequate evidence to suggest that personal involvement in moral judgement is sufficient for emotional arousal. Moreover, when moral emotional and non-moral emotional content are explicitly contrasted, the vmPFC appears to be implicated in implicit moral judgements independent of whether they are experienced as more or less emotional. One possibility, then, is that the vmPFC is critical to the moral judgement itself, and is associated more with the difficulty of such judgements than with their emotionality. As we shall see in the next section, similar cognitive explanations may also account for some of the findings in the decision-making and formal reasoning literature. Perhaps it is most likely that our judgements involve a complex interplay of cognitive and emotional factors, but further work is needed to elucidate the precise role that vmPFC plays in each.

Theoretical accounts of how emotions may influence reason through vmPFC

There are several theoretical accounts of emotional influences on reasoning, many of which are covered in this volume. Despite this, there has been little development of neural mechanistic models of such influences over the last 15 years. Below we briefly discuss two accounts, the Somatic Marker Hypothesis, and emotional influences on heuristic strategies, which may provide the best link to the neuropsychological literature to date.

Use of somatic markers through vmPFC

In an attempt to explain the precise deficits exhibited by vmPFC-damaged patients, Damasio and colleagues developed the Somatic Marker Hypothesis (SMH) as a neurobiological account of normal emotional influences on reasoning. The SMH proposes that emotional feelings, which are the mental representation of changes perceived in the body and brain during an emotional response, tag particular behaviours or judgements (i.e., that led to the response) with an emotional marker – or somatic marker. These tags are learned through experience and provide the decision-maker with information about the expected emotional consequences of future actions. In other words, these tags tell us how good or bad we are likely to feel if we decide to make the same choices again in the future. At the time of this later choice, these markers are retrieved, generating a conscious or unconscious anticipatory *re-experience* of the original emotional feeling, and subsequently biasing behaviour. It is suggested that this re-experiencing can occur either as part of a body-loop, by reinitiating a response in both body and brain, or through an 'as-if-body-loop', whereby the mental representations reproduce the emotional feeling without involving the body-proper.

These anticipatory responses may be particularly useful when decision-making involves high uncertainty, i.e., when the decision-maker is unsure about the likelihood of the potential consequences of behaviours. This is because they allow for some decision options (perhaps those that are most unambiguously good or bad) to be promptly eliminated from further consideration,

such that we may either choose the best option there and then, or focus our efforts towards evaluating the remaining uncertain options. Somatic markers may also be of special use when an affect-free cost-benefit analysis reveals no clear reason to prefer one decision option over another. In such cases, even very subtle anticipatory emotional responses can act as the only guide to choice by tagging options with positive and negative reinforcement. In these ways, somatic markers can allow for decisions to be reached more quickly and efficiently, and in a more consistently goal-directed fashion.

Damasio's account is unique in its focus on the neurobiology of emotion–reason interactions. It is suggested that the vmPFC is vital for retrieving these somatic markers during decision-making, such that vmPFC damage results in both a lack of learned anticipatory emotional feeling and its resulting impact on reasoning and decision-making (Bechara et al., 1994; Damasio, 1994). More precisely, while patients with vmPFC damage still have the capacity to perform an affect-free cost-benefit analysis, they are unable to use emotional feelings to guide their responses.

It is worth noting also that Damasio emphasizes a critical distinction between the emotion itself and the 'feeling' of the emotion, which is 'a composite image' of the changes in the body and brain during the emotional experience. The feeling comes from the 'mental states that arise from the neural representation of the collection of responses that constitute an emotion within the brain structures appropriate for such a representation' (Damasio, 2000), and the SMH proposes that it is the reactivation of this *feeling* that is used to guide behaviour, and not a reactivation of the *emotion* itself. A key component to the SMH, then, is that somatic markers are learned through experience and re-initiated prior to later choices, allowing the decision-maker to 'feel' which options might prove most advantageous. Moreover, the hypothesis suggests that these anticipatory responses during reasoning and choice may bypass the body entirely, and be 'felt' through an 'as-if-body-loop'. This begs the question: are these truly emotional responses, or simply mental imagery and/or memory

retrieval processes? Is it possible that vmPFC involvement in reasoning is driven by an influence of cognitive processes, such as learning and memory, with no need to consider emotion at all?

Other theories have similarly supported a critical role for 'gut feelings' in reasoning, although not always with a direct appeal to emotion (e.g., Gigerenzer, 2007). On a second look, the SMH's reliance on learning and memory hints that it may indeed be cognitive, rather than affective, processes that are directly influencing reasoning. As such, the role of vmPFC in reasoning and decision-making may be a cognitive role.

Some critics of the SMH have similarly searched for cognitive explanations. They have particularly focussed on the many non-affective processes that seem to be involved in IGT performance which, if disrupted, may explain the performance impairments after vmPFC damage. If such processes are unrelated to emotion, and yet still explain the patient findings, then this could seriously undermine our focus on vmPFC as underlying emotional influences on reason. For example, some evidence suggests that the impaired IGT performance shown by vmPFC-damaged patients is associated with abnormal risk assessment and risk preference (e.g., Tomb, Hauser, Deldin, & Caramazza, 2002). The critical role of reinforcement learning or response reversal in the original version of the IGT has also raised concerns. In the original version of the IGT, the risky decks are always more advantageous in early trials than are the safer decks, and only become disadvantageous over time. To do well in the task, then, the decision-maker must be able to inhibit their early learned stimulus-reward associations in the light of the new information – as in reversal learning. It has been shown that ventral PFC is involved in both the acquisition and reversal of stimulus-reward associations (Dias, Robbins, & Roberts, 1996; Mishkin, 1964; Rolls, 2000), although it may be the more lateral regions which are important in reversal learning and inhibition (Elliott, Dolan, & Frith, 2000; Iversen & Mishkin, 1970). Fellows and Farah (2003) found that vmPFC-damaged patients have problems with reversal learning, but not with initial associative learning, and that this deficit was associated with their real-world social difficulties. In a later study, Fellows and Farah removed

the reversal learning component from the IGT, by shuffling the original trial order, and found that vmPFC patients can perform just as well as controls (Fellows & Farah, 2005). While such findings may seem to undermine a role for emotional processes in IGT performance, other studies have shown that vmPFC is similarly important in preference-driven decision tasks which are designed to be similar to the IGT but with reduced learning demands and working memory demands (Rogers et al., 1999).

In the moral reasoning domain, cognitive explanations have also been offered to explain the observed involvement of vmPFC. Greene et al. (2001) found that participants were slower to respond to personal moral judgements than to impersonal moral judgements, which they argued may reflect a need to overcome an emotional response to the dilemma. However, this slowing of response time may point to increased cognitive conflict rather than emotional conflict. Moreover, Ciaramelli et al. (2007) found that such response slowing (to personal moral reasoning) was not evident in their vmPFC-damaged patients in a similar task, and Koenigs et al. (2007) found that vmPFC damage only affected moral judgement when conflict was high. Together these data might suggest that the role of vmPFC in personal moral reasoning may be associated with demands on computational capacity, rather than requiring an emotional explanation.

Emotions as influencing heuristic processes in vmPFC

One possibility, implied by the above logical reasoning findings, is that emotions may change the extent to which we rely on prior beliefs when reasoning and deciding. Intriguingly, such interactions may be overlooked in typical preference-driven decision-making tasks, where beliefs and logic are typically not varied orthogonally to each other, and indeed where judgements are often naturally associated with the decision-maker's prior beliefs. Emotion, belief and logical validity appear to interact at many levels, e.g., beliefs commonly bias our judgements of validity (Evans, Barston, & Pollard, 1983), the believability of a statement influences its rated pleasantness (Nicolle

& Goel, 2012), valid arguments are found to be more likeable than invalid arguments (Morsanyi & Handley, 2011), and conclusions that are valid, believable, fluent or most accessible are associated with a pleasurable 'feeling of rightness' (Thompson & Morsanyi, 2012). Emotions have also been shown to influence the strength of belief-bias effects in reasoning (De Jong, Weertman, Horselenberg, & van den Hout, 1997; Goel & Vartanian, 2011; Stollstorff, Bean, Anderson, Devaney, & Vaidya, 2012; Vroling & De Jong, 2009). As such, emotional influences on reason could occur either directly, or through an influence on beliefs and/or how they are used in reasoning and deciding. While work on the influence of emotion on belief-biased reasoning from a neuroscience perspective is scarce, this is an exciting avenue for future research exploring emotional influences on reason.

The finding (described above) that reciprocal responses in vmPFC and dlPFC reflect the degree to which reasoning is emotional (Goel & Dolan, 2003a), is in keeping with a dual-process account in which emotionally salient reasoning recruits relatively more vmPFC activity while emotionally neutral reasoning recruits relatively more dlPFC activity. Similar dual-mechanism accounts have been used to explain the moral reasoning findings (described above), and also support a role of reciprocal vmPFC and dlPFC activity (Greene, Nystrom, Engell, Darley, & Cohen, 2004; Haidt, 2001). However, in a study in which *only* emotionally *neutral* content was used, Goel and Dolan (2003b) also found greater vmPFC activity when reasoning is biased by prior beliefs than when it is not, while dlPFC is more active when we are able to overcome our prior beliefs. Since this study involved no emotional manipulation, how might we understand this similar involvement of vmPFC in *both* emotion-biased and belief-biased reasoning?

According to dual-process accounts, there are two types of processing which may be employed in reasoning and decision-making. Type 1 processes are effortlessly engaged and react based on responses learned from past experience. Processes of this kind are often described as stemming from a heuristic mechanism. In contrast, Type 2 processes are controlled, deliberative and

able to generalize to novel or hypothetical scenarios. They comprise an analytical processing mechanism. While the two types of processing can occur in parallel, Type 1 processes are thought to have temporal priority and will prevail unless Type 2 processes intervene and modulate the behavioural result of Type 1 processes, e.g., if the Type 1 response is recognized to be inappropriate for the problem at hand, or if no Type 1 process can be initiated (e.g., in completely novel scenarios). Emotion itself is not typically thought to be the key factor distinguishing Type 1 from Type 2 processes. Instead, emotion is commonly considered as just one of many biasing devices (heuristics) that may be relied upon by Type 1 processes. As such, affect can provide us with a route to judgement that is quicker and less computationally intensive than the more analytical routes. Emotion may either act to bias behaviour directly, or otherwise may be a powerful influence on whether or not we will respond through a heuristic route rather than through the analytical route.

Some heuristic processes are proposed as being primarily based on affect, e.g., Slovic et al.'s 'affect heuristic' (Slovic, Finucane, Peters, & MacGregor, 2007) and Sunstein's 'moral heuristics' (Sunstein, 2005), which are both said to provoke judgement without the necessary involvement of cognitive deliberation. Indeed, it has been suggested that *all* heuristic processing may be 'intimately associated with the experience of affect' (Epstein, 1994). If this is the case, then a vmPFC role in all heuristic processing (even when no clear emotional content is present) may always be underwritten, in some way, by an affective response. However, heuristic routes to thinking are not commonly defined as emotional and many heuristic processes may be entirely affect-free. On such an account, it is possible that vmPFC could provide an important source of emotional input into the reasoning process, but only in as far as emotion merely supplies us with *information* about expected value (akin to any other informational content of the cognitive system). Information processing is typically considered to be cognitive, and not affective (Newell, 1980).

On top of this, heuristics are learned through past experience, relying on consistencies within our environment to predict which behaviours have the highest likelihood of being beneficial with the

least amount of risk or effort. This learned component is in striking resemblance to the Somatic Marker Hypothesis, in which somatic markers are learned through experience and re-initiated at later choices to allow the decision-maker to 'feel' which options might prove most advantageous. Gigerenzer's (2007) proposed role of 'gut feelings' in reasoning is, in many ways, comparable to both Slovic's suggested 'affect heuristic' and to Damasio's 'somatic markers'. Yet, despite the term 'feeling' being typically reserved for the description of affective processing, Gigerenzer argues that these heuristic influences on our behaviour require no emotional interpretation. According to such accounts, emotion itself may have no direct effect on our behaviour.

Are we really giving emotion a "second chance"?

It is indeed intriguing that the vmPFC is commonly implicated in the studies described above, despite the large differences in research approach and the types of tasks used. This work has led many to argue for a critical role of vmPFC in emotional influences on reason. However, we have also seen that there remain multiple possible interpretations of these findings, not least that some of the results may be attributed to cognitive, rather than affective, factors. As such, there may still be no clear-cut connection between emotion and the role of vmPFC in reasoning and decision-making.

What is perhaps of even greater concern is that we may also question the role of emotion in theoretical accounts of 'emotional' influences on reason, such as the SMH. Specifically, it is not always obvious the extent to which emotion is even considered to be casual in these theories. We have already seen above that the SMH puts its emphasis on a role of anticipatory emotional feeling, the re-experienced mental representation of the emotion, rather than on the emotion itself. Moreover, the SMH appears to be rather more reliant on learning and memory processes than on affect. For the SMH to be a theory of emotional influences on reason, the emotion itself must have a direct causal role in the reasoning and deciding process. To what extent does the SMH view such influences as

affective, rather than cognitive? Given that a precise definition of emotion is still somewhat elusive, this may be a very difficult question to answer. Critically, to clearly distinguish emotional influences on reasoning from cognitive influences, we must consider *emotion as emotion*. That is, emotion must be considered not only as having representational content, but also as possessing valence and arousal components. In stark contrast, many theoretical accounts of emotional influences on reason consider only *emotion as information*, i.e., dealing with its representational component and ignoring valence and arousal (Simon, 1967). This is arguably the case for the SMH, as well as other 'affect-as-information' accounts, whereby emotions provide the decision-maker with value information, which is then used to guide choice. In heuristic processing accounts, it may also be argued that emotion provides a source of information for the decision-process, in a way that is relatively faster and more effortless than the information provided through the analytical processing route. Characterizing emotion as information not only requires that we first determine precisely how the language of emotion is translated into the language of the cognitive system, but it also transforms emotion into informational content akin to any other informational content of the cognitive system. If we are interested in emotional influences on reason, surely we should treat emotion with the respect it deserves, i.e., we must give a causal role to valence and arousal beyond that of representational content. Theoretical accounts of emotional influences on reason, then, must be more explicit in their stance on this issue.

While the causal efficacy of cognitive states derives from their semantics (or at least syntax), the causal efficacy of emotions may derive from their bodily instantiation. Valence may bias the reasoning process in one direction or another, while arousal energizes the system, through heightened mental and physiological activity, and readies the body for action. Findings that positive and negative emotions often have similar influences on reasoning suggest that their impacts may be driven primarily by the arousal component of emotion, rather than valence (e.g., Blanchette, 2006; Blanchette & Richards, 2004). The presence of a physiological arousal component to the types of

influences described in this chapter (and throughout this volume) may provide key insight into the extent to which such influences are truly affective. If anticipatory arousal is indeed found to have a direct impact on the reasoning and decision-making process, and if this impact depends on responses in vmPFC, then this may provide the strongest evidence so far for the role of vmPFC in emotional influences on reason. Unfortunately, to date, the empirical data on this issue is sparse and highly ambiguous.

The conscious experience of arousal may, at some level, be accessible through subjective ratings. However, physiological arousal can also be tapped directly through measuring skin conductivity responses (SCRs), pupil dilation, heart rate, and muscle tension. In the logical reasoning domain, SCRs are found to correlate negativity with reasoning ability, such that greater responses to emotional content are associated with a reduced tendency to respond logically (Blanchette & Leese, 2011). No studies of arousal and logical reasoning have yet been performed from a neuroscience perspective, however. In healthy individuals playing the IGT, anticipatory skin conductance responses prior to choosing from the bad card decks are associated with improved performance in the task (i.e., greater tendency to avoid the risky decks), and normal SCRs are associated with vmPFC activity. As introduced previously in this chapter, vmPFC-damaged patients, on the other hand, show neither the anticipatory physiological responses nor the improved performance. Since these data support only a correlational role of skin conductivity in decision-making, we cannot rule out the possibility that these responses may be associated rather with cognitive evaluations of expected outcome, level of risk or ambiguity, reinforcement learning or memory retrieval. To fully understand a potential role of emotion, through the vmPFC, in reasoning and decision-making, it is vital that we explore whether arousal plays a causal role in shaping the reasoning and decision process itself. Bechara, Damasio et al. argue that arousal must play such a causal role, since anticipatory SCRs can occur prior to any conscious awareness of the appropriate strategy in the IGT, and yet bias choice behaviour (but see Maia & McClelland, 2004; and Persaud, McLeod, & Cowey, 2007). However,

there are healthy participants who are able to perform well on the IGT, but who do not show the typical anticipatory SCRs, and others who do not learn appropriate behaviour but yet show the SCR effect (Crone, Somsen, Beek, & Van Der Molen, 2004), suggesting that anticipatory physiological arousal may neither be necessary nor sufficient for decision-making.

Some work has attempted to address the causal role of arousal by observing the reasoning abilities (particularly in IGT performance) of individuals with impaired peripheral feedback. Peripheral feedback informs the brain as to the state of the body, and disruptions in such feedback may mean that the brain is unable to use anticipated physiological arousal in the process of reasoning and deciding. If such disruptions are observed in these patients, this work would provide some of the best support for a causal effect of arousal on reason, and yet the support from this work is weak. For example, individuals with peripheral nerve damage have actually been found to show *improved* IGT performance relative to healthy controls (Heims, Critchley, Dolan, Mathias, & Cipolotti, 2004), although the sample size was small and these individuals did have other intact sources of peripheral feedback to the brain. Patients with spinal cord damage have also failed to show impairments in the IGT (North & O'Carroll, 2001). In the case of moral reasoning, however, there are findings that false physiological feedback can influence moral judgements (Batson, Engel, & Fridell, 1999), which hints toward some causal role of arousal. Finally, in the case of the SMH, it is yet unclear as to the extent to which physiological input actually *needs* to be causally involved in the decision process, since the hypothesis also allows for emotion to play its role through an 'as-if loop' which bypasses the body altogether. As such, it is unclear the extent to which vmPFC involvement, according to the SMH, is assumed to hinge on arousal. Future work may need to also address the causal role of these as-if responses, perhaps only accessible through self-report or neuroimaging.

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