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Functional and clinical neuroanatomy of morality

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Morality is among the most sophisticated features of human judgement, behaviour and, ultimately, mind. An individual who behaves immorally may violate ethical rules and civil rights, and may threaten others' individual liberty, sometimes becoming violent and aggressive. In recent years, neuroscience has shown a growing interest in human morality, and has advanced our understanding of the cognitive and emotional processes involved in moral decisions, their anatomical substrates and the neurology of abnormal moral behaviour. In this article, we review research findings that have provided a key insight into the functional and clinical neuroanatomy of the brain areas involved in normal and abnormal moral behaviour. The 'moral brain' consists of a large functional network including both cortical and subcortical anatomical structures. Because morality is a complex process, some of these brain structures share their neural circuits with those controlling other behavioural processes, such as emotions and theory of mind. Among the anatomical structures implicated in morality are the frontal, temporal and cingulate cortices. The prefrontal cortex regulates activity in subcortical emotional centres, planning and supervising moral decisions, and when its functionality is altered may lead to impulsive aggression. The temporal lobe is involved in theory of mind and its dysfunction is often implicated in violent psychopathy. The cingulate cortex mediates the conflict between the emotional and the rational components of moral reasoning. Other important structures contributing to moral behaviour include the subcortical nuclei such as the amygdala, hippocampus and basal ganglia. Brain areas participating in moral processing can be influenced also by genetic, endocrine and environmental factors. Hormones can modulate moral behaviour through their effects on the brain. Finally, genetic polymorphisms can predispose to aggressivity and violence, arguing for a genetic-based predisposition to morality. Because abnormal moral behaviour can arise from both functional and structural brain abnormalities that should be diagnosed and treated, the neurology of moral behaviour has potential implications for clinical practice and raises ethical concerns. Last, since research has developed several neuromodulation techniques to improve brain dysfunction (deep brain stimulation, transcranial magnetic stimulation and transcranial direct current stimulation), knowing more about the 'moral brain' might help to develop novel therapeutic strategies for neurologically based abnormal moral behaviour.

Introduction

Abnormal moral behaviour implies the violation of ethical rules and civil rights and often results in violence and criminal acts. Moral behaviour is the product of a complex process that although somehow primed by genes and environment, is ultimately controlled by the brain. Since the 1990s, both behavioural and neuroscientific studies of morality have grown in volume and sophistication. In particular, the interest in the neurobiological determinants of human ethics prompted neuroscientists to address several intriguing issues, including whether specific neuronal networks or anatomical brain structures exist for moral behaviour. Besides bringing about a major advance in neuroscience and in the biology of mind, understanding the neural foundations of morality could help in developing novel strategies for treating abnormal moral behaviours. It also has potentially important social implications. For instance, developing a treatment for serial sexual assaulters could help prevent further crimes, reduce the number of victims and diminish the need for imprisonment and ultimately, benefit society.

In this article, to understand better the functional and clinical neuroanatomy of morality, we review and integrate findings from studies in various fields (clinical neurology and psychiatry, neuroimaging, neurophysiology, neuropathology, behavioural genetics and psychoneuroendocrinology) investigating moral judgement, moral behaviour and violent behaviour, considered as the behavioural expression of moral abnormality. Unlike previous reviews on morality (Moll *et al.*, 2005; Raine and Yang, 2006; Young and Koenigs, 2007; Funk and Gazzaniga, 2009; Huebner *et al.*, 2009; Moll and Schulkin, 2009), we discuss studies on healthy subjects and on patients with neurological and psychiatric disorders through a neuroanatomical approach. To highlight the complexity and multiple faceted neural control of morality we also consider the role of genes and hormones. Although abnormal moral behaviour can be part of several neurological and psychiatric disturbances, for the purposes of this review we focus on conditions primarily characterized by violent behaviour that could be attributed to moral abnormality.

Violence as the behavioural consequence of moral abnormality

Several tests can now be used to measure morality in experimental studies (tasks that use philosophical moral dilemmas, tasks that present visual sentences and tasks that present pictures) (Greene *et al.*, 2001; Moll *et al.*, 2001; Harenski and Hamann, 2006), and for clinical purposes, scales and questionnaires are available to assess abnormal moral behaviour (Rush *et al.*, 2008).

From a behavioural point of view, the major consequence of moral abnormality is violence. Violence stems from multiple factors including social learning, frustration, cognitive and moral development, mental and neurological disorders, environmental and genetic factors (Fabian, 2010). Their cumulative effect portends

a behaviourally negative outcome, such as psychopathy, criminality, murder, substance abuse disorder, homelessness and unemployment (Fabian, 2010). Aggression can be defined as 'any form of behaviour directed towards the goal of harming or injuring another living being who is motivated to avoid such treatment' (Baron and Richardson, 2004). Aggression can be secondary to focal cerebral disease or related to brain abnormalities in individuals with no other overt signs of a cerebral disorder (David *et al.*, 2009). Aggression becomes violence when it is exaggerated and unjustifiable, leading to violation of social norms and to destruction (Victoroff, 2009). To fulfil the aims of this review, among psychiatric disorders we will consider psychopathy, sociopathy and antisocial personality disorders. A critically important denominator shared by all these conditions is the failure to conform to the commonly accepted mores of society that often ultimately results in abnormal moral behaviour.

Frontal lobe

Healthy subjects

Neuroimaging studies demonstrate that a brain region closely involved in moral judgement is the ventromedial prefrontal cortex (Greene *et al.*, 2001; Moll *et al.*, 2001, 2002*a*, *b*; Heekeren *et al.*, 2003; Borg *et al.*, 2006; Harenski and Hamann, 2006; Luo *et al.*, 2006; Prehn *et al.*, 2008; Harenski *et al.*, 2009; Young and Saxe, 2009; Shenhav and Greene, 2010; Sommer *et al.*, 2010). The ventromedial prefrontal cortex has a critical role in encoding the emotional value of sensory stimuli (Rolls, 2000), and its recruitment during moral decisions supports ventromedial prefrontal cortex involvement in their emotional processing (Greene *et al.*, 2001; Moll *et al.*, 2002*a*, *b*; Heekeren *et al.*, 2003). The ventromedial prefrontal cortex is also implicated in allowing one to adhere to social norms and cultural values (Moll *et al.*, 2005), and in representing preferences about others' outcomes according to perceived intentions (Cooper *et al.*, 2010). The left ventromedial prefrontal cortex is more intensely activated in subjects with lower ability to apply moral principles in justifying the resolution of moral dilemmas (Prehn *et al.*, 2008). Ventromedial prefrontal cortex/medial orbitofrontal cortex activation also correlates with the 'expected moral value' of decision options, defined as the expected number of lives lost/saved (Shenhav and Greene, 2010). Promising research developments over recent years include studies designed to modulate moral judgement with non-invasive brain stimulation techniques [transcranial direct current stimulation (tDCS) and transcranial magnetic stimulation] over the different areas of the frontal lobe. tDCS entails applying weak direct currents through an electrode on the scalp for a time ranging from seconds to minutes (Fox, 2011). This technique induces prolonged changes in cortical excitability: anodal stimulation generally increases and cathodal stimulation decreases cortical excitability (Priori, 2003; Utz *et al.*, 2010), respectively depolarizing or hyperpolarizing the neuronal membrane (Accornero *et al.*, 2007). When Koenigs *et al.* (2009) delivered bilateral prefrontal tDCS to 25 subjects doing a moral judgement task they failed to obtain statistically significant results. In a study conducted in our

laboratory (Fumagalli *et al.*, 2010), we administered a moral judgement task to 78 healthy subjects before and after anodal or cathodal tDCS applied over the ventral prefrontal cortex or occipital cortex. In female subjects, we found that, whereas anodal prefrontal tDCS significantly increased utilitarian responses, cathodal prefrontal tDCS tended to decrease them. According to Greene *et al.* (2008) and Greene (2007), a utilitarian choice aims at 'maximizing benefits and minimizing costs across affected individuals' (Greene *et al.*, 2008), 'endorsing harmful actions that promote the greater good' (Greene, 2007). Hence, anodal ventral prefrontal tDCS interferes with utilitarian decisions specifically in females. We hypothesized that anodal stimulation reduces the prefrontal activity in emotional evaluation and does so by mimicking the effect of a lesion. A possible explanation for gender difference is that tDCS modulates the female tendency towards altruism more easily than the male tendency. Whereas altruism in males 'resists' tDCS-induced changes, altruism in females might be more sensitive to small, transient changes induced by stimulation. Because dopamine is an anionic catecholamine that migrates towards the anode during electrophoresis, anodal ventral prefrontal tDCS might act by increasing dopamine levels in the frontal lobe, thus influencing the dopamine reward circuit and ultimately altering decisional processes, increasing utilitarian response rates. Though several methodological reasons make it difficult to compare the study conducted by Koenigs *et al.* (2009) with the one conducted in our laboratory (Fumagalli *et al.*, 2010), our finding provides new evidence that brain stimulation (tDCS) is able to modulate moral judgement and behaviour (at least under laboratory conditions).

The rational counterpart of the ventromedial prefrontal cortex is the dorsolateral prefrontal cortex. This frontal lobe area is involved in problem-solving and cognitive control (Greene *et al.*, 2004) and competes with the ventromedial prefrontal cortex in suppressing prepotent emotional reactions (Greene *et al.*, 2004). Specifically, in moral judgement the dorsolateral prefrontal cortex has a pivotal role in aggregating cost-benefit analysis and in utilitarian moral reasoning (Greene *et al.*, 2001, 2004), intervenes in evaluating situations that recruit rule-based knowledge (Prehn *et al.*, 2008), and in deciding on responsibility for crimes and on appropriate punishment (Haushofer and Fehr, 2008). The dorsolateral prefrontal cortex is also activated during dishonest behaviour, probably reflecting the process of lying (Greene and Paxton, 2009). tDCS over the dorsolateral prefrontal cortex also influences deceptive responses (Priori *et al.*, 2008; Mameli *et al.*, 2010).

Other brain regions involved in moral processing are the cingulate cortex (Greene *et al.*, 2001, 2004; Harenski *et al.*, 2008) and the left subgenual gyrus (Luo *et al.*, 2006). The anterior cingulate cortex mediates the 'conflict' between the emotional and the rational components of moral reasoning, whereas the posterior cingulate cortex is more closely related to emotion and social ability (Greene *et al.*, 2001, 2004).

In conclusion, data in healthy subjects show that the frontal lobe drives moral behaviour and that the role of the various frontal areas probably differs during moral decision processing: whereas the orbital and ventromedial prefrontal cortices emotionally drive moral decisions, the dorsolateral prefrontal cortex acts mainly as a rational 'filter'. This dual opposite processing involving the ventromedial prefrontal cortex and the dorsolateral prefrontal cortex seems to be mediated by the anterior cingulate cortex.

Patients

The first clinical evidence showing a link between personality, behaviour, morality and the frontal lobe came from studies on patients. In 1848, while Phineas Gage was working on a railroad line, an accidental explosion drove a steel rod up into his left cheek and through his frontal lobes. A local physician, Harlow, described him as fitful, irreverent, impatient of restraint or advice when it conflicts with his desires, and also obstinate and capricious (Feldman and Goodrich, 2001). In 1936, on the basis of animal experiments conducted by John Fulton, Egas Moniz proposed surgically cutting the connections between the frontal cortex and the thalamus (leucotomy) to treat certain psychoses (Heller *et al.*, 2006). In his article on psychosurgery, Moniz reported good results also in severely agitated, anxious or depressed patients (Moniz, 1937). Quenching the original enthusiasm for brain surgery as a viable means of combating mental illness, in 1942 Walter Freeman reported the results for 200 lobotomy cases and acknowledged that the procedure was not always benign: 14% of the patients who underwent prefrontal lobectomy subsequently manifested seizures and impaired cognition, affect, mood and social behaviour (Feldman and Goodrich, 2001). After surgery these patients also exhibited a severe frontal syndrome, altered abstract thinking and judgement (Feldman and Goodrich, 2001), and various personality changes. Freeman described patients as

> '...lazy, rude, boisterous, restless and inane [...] [the patient] is relatively unteachable, having lost those social skills that are necessary for living outside an institution [...]. If the patient has previously demonstrated antisocial traits such as alcoholism, drug addiction, criminality, avoidance of responsibility, aggressiveness or psychopathic activities, the effect of operation may be to free him from any residual sense of guilt or shame, and thus turn loose upon society an individual whose behavior is intolerable' (Freeman, 1950).

Hence, surgical procedures involving the frontal cortex and frontal tracts reportedly achieved successes or failures: the symptoms were reduced or, conversely, as Freeman reported, exacerbated. The main reason for these opposing results is probably the lack of homogeneity in the procedures used by Moniz and Freeman (Freeman, 1950; Knight, 1969). The lack of neuroimaging techniques, the psychopathological heterogeneity of patients, the lack of quantitative outcome variables and of neuropathological controls in studies reporting the results of frontal leucotomy and other psychosurgical interventions make it difficult to understand from historical data how surgery affects the frontal lobe in humans. Whatever the clinical results, surgery and lesions of the frontal lobe can induce moral changes thus further demonstrating the key role of this structure in moral behaviour.

Reviewing 25 previously published studies of post-lesion acquired antisocial personality disorders and 39 studies of post-lesion acquired obsessive–compulsive disorders, Braun *et al.* (2008)

found that the most typical lesion causing antisocial personality disorder is that involving the ventromedial prefrontal cortex, occasionally spreading to the caudate nucleus (Braun *et al.*, 2008). In an early study by Feuchtwanger (1923) cited in David *et al.* (2009), comparing patients with frontal gunshot wounds with patients in whom bullets penetrated other parts of the skull, frontal lesions induced euphoria, irritability, aggressivity, apathy, attention deficits and moral defects (David *et al.*, 2009). Acquired lesions to the frontopolar and to the ventromedial prefrontal cortex at an early age may lead to even more severe impairments in moral behaviour, suggesting that the prefrontal cortex is involved in moral development (Eslinger *et al.*, 1992; Anderson *et al.*, 1999). Patients with ventromedial prefrontal cortex lesions also have a significantly high frequency of moral disturbances with aggressive and violent behaviour. They also typically seem disinhibited, impulsive and unconcerned with the consequences of their behaviour (Rolls *et al.*, 1994; Grafman *et al.*, 1996; Brower and Price, 2001), a neurological syndrome significantly defined as 'acquired sociopathy' (Saver and Damasio, 1991). These observations are consistent with animal studies showing that lesions in the orbitofrontal cortex are related to uncontrolled aggression (Butter *et al.*, 1970; Elliott, 1990). Patients with ventromedial prefrontal cortex damage retain the knowledge of social rules, recognize the elements that compose social situations, for example current contingencies, possible response options and future outcomes (Saver and Damasio, 1991), but they cannot make appropriate decisions in natural settings. This inadequate decisional processing makes them insensitive to the future positive or negative consequences of an action. The 'somatic marker model' explained the reduced anticipatory skin conductance in response to stimuli predicting negative outcomes observed in these patients as an inability to mark the implications of a decision with a signal that automatically distinguishes advantageous from pernicious actions (Damasio *et al.*, 1990; Damasio, 1994). Systematic studies about the impairment of social and moral behaviour related to damage to the ventromedial prefrontal cortex reported various explanations. For example they proposed that moral judgements in these patients are characterized by an abnormal high rate of utilitarian judgements for moral dilemmas in which social emotions play a pivotal role in resolving moral conflict (Ciaramelli *et al.*, 2007; Koenigs *et al.*, 2007; Moretto *et al.*, 2009; Thomas *et al.*, 2011) or by more morally permissive judgements for failed attempts to harm (Young *et al.*, 2010b). Focusing on how patients justify moral judgements, others suggest that patients' justifications do not reflect normal adult levels of moral reasoning but are characterized by egocentrism (Anderson *et al.*, 1999).

The 'somatic marker model' and these data suggest that moral reasoning relies on both rational/conscious and emotional/unconscious processing in the ventromedial prefrontal cortex. Prefrontal involvement, measured in terms of reduced grey matter in this area, is also reported in antisocial and psychopathic individuals (Raine *et al.*, 2000; Yang *et al.*, 2005), and in aggressive patients with temporal lobe epilepsy (Woermann *et al.*, 2000). In the neuroimaging literature, reduced prefrontal glucose metabolism is associated with acts of aggressive impulsive behaviour (Goyer *et al.*, 1994), with antisocial personality disorder (Bufkin and Luttrell, 2005), and characterizes murderers compared with normal controls (Raine *et al.*, 1994). Superior and ventrolateral prefrontal activity also positively correlated with psychopathy in an emotion regulation task (Harenski *et al.*, 2009), whereas in moral/non-moral picture distinctions, ventromedial prefrontal cortex activity is more severely reduced in psychopaths than in non-psychopaths (Harenski *et al.*, 2010) (Fig. 1). New imaging evidence for the neural bases of moral and prosocial sentiments comes from a study in patients with the behavioural variant of frontotemporal dementia engaged in a moral sentiment task that highlighted a role of the medial frontopolar cortex (Moll *et al.*, 2011).

Anterior cingulate cortex lesions result in persistent behavioural changes, in particular reduced and occasionally increased aggressivity, disinhibition, impulsivity, emotional blunting and decreased motivation (Devinsky *et al.*, 1995).

Current knowledge from studies in patients therefore suggests that the frontal structures most directly involved in abnormal moral behaviour are the medial orbitofrontal cortex and ventromedial prefrontal cortex.

Temporal lobe and insula

Healthy subjects

A further important structure for moral behaviour is the temporal lobe. Neuroimaging studies found that a temporal lobe region involved in moral judgement is the superior temporal sulcus (Moll *et al.*, 2001, 2002a, b; Heekeren *et al.*, 2003, 2005; Greene *et al.*, 2004; Borg *et al.*, 2006; Harenski and Hamann, 2006). Superior temporal sulcus activates during the elaboration of moral dilemmas because it is associated with emotion (Greene *et al.*, 2004), during processing of social cognition mechanisms (Moll *et al.*, 2002b; Greene *et al.*, 2004) and in making decisions about complex ethical dilemmas (Heekeren *et al.*, 2003; Greene *et al.*, 2004).

Another region implicated in moral function includes the anterior/middle temporal gyrus (Moll *et al.*, 2001; Heekeren *et al.*, 2003, 2005; Greene *et al.*, 2004; Harenski and Hamann, 2006; Sommer *et al.*, 2010). Accordingly, some researchers retain that these areas are activated after the point of decision, in particular when subjects choose a utilitarian response, suggesting that neural processing of moral conflict is associated with higher cognitive demands (Greene *et al.*, 2004; Sommer *et al.*, 2010).

A further temporal region activated during moral dilemma evaluation (Greene *et al.*, 2001) and involved in evaluating moral agency and responsibility (Borg *et al.*, 2006) is the angular gyrus.

The temporo-parietal junction (Young *et al.*, 2007; Kedia *et al.*, 2008; Harenski *et al.*, 2009; Young and Saxe, 2009) contributes to moral intuition (spontaneous, unsolicited attention directed towards cues that have potential moral salience such as a person in distress, weapons or emotion-laden words) (Harenski *et al.*, 2009), and to belief attribution during moral judgement (Young *et al.*, 2007; Young and Dungan, 2011). Neurostimulation studies also support a direct link from theory of mind to moral judgement. Theory of mind is a person's intuitive ability to understand other
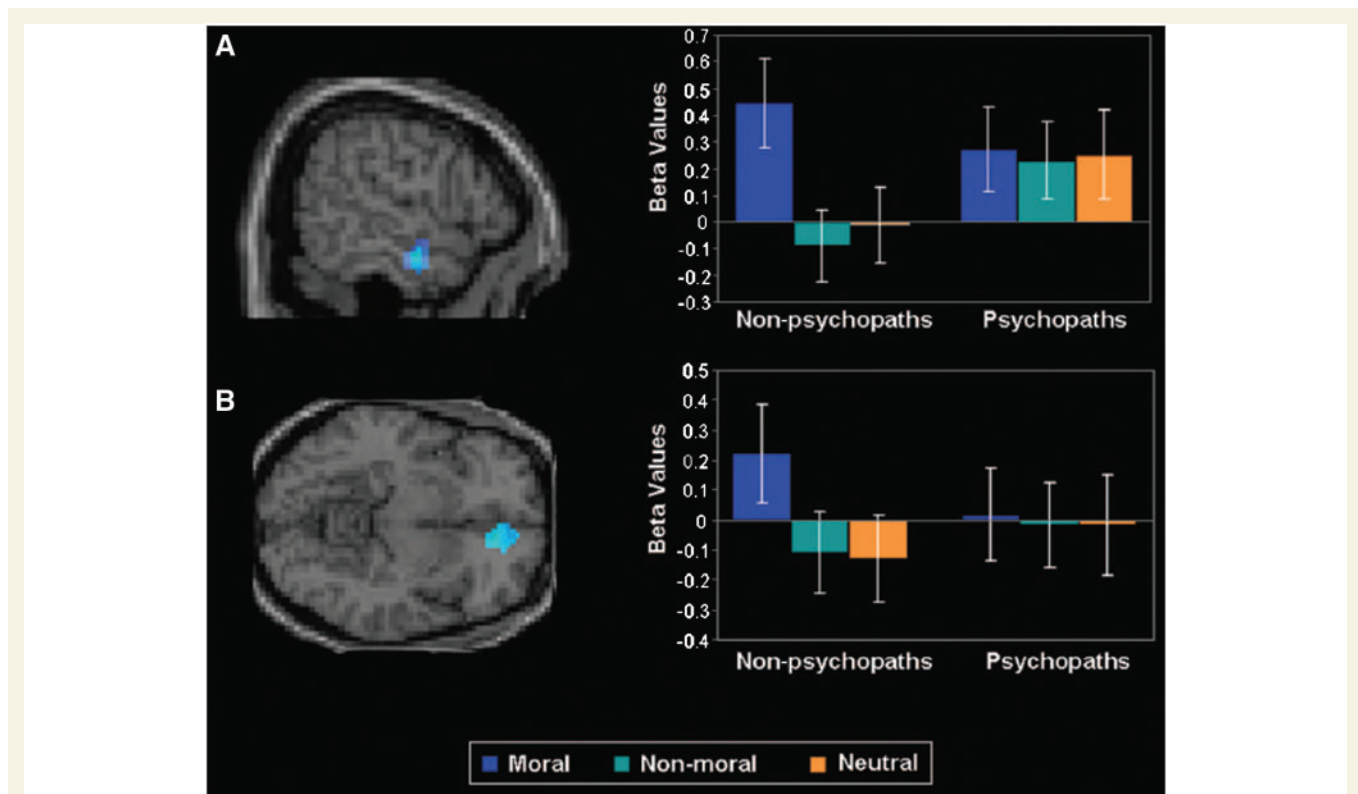
Figure 1 Analyses of brain activity during moral picture viewing showed a significant interaction between psychopaths/non-psychopaths and moral versus non-moral and neutral picture viewing in the anterior temporal cortex (**A**) and in ventromedial prefrontal cortex (**B**). This finding indicates that non-psychopaths showed a significantly greater moral than non-moral and neutral picture distinction in these regions, whereas psychopaths did not. Error bars are standard errors. (Copyright © 2010 by the American Psychological Association. Reproduced with permission from Harenski *et al.*, 2010. The use of APA information does not imply endorsement by the APA).

people's plans, thoughts, points of view, beliefs, attitudes and emotions. Transcranial magnetic stimulation applied to the right temporo-parietal junction before or during a moral judgement task led subjects to rely less on the actor's mental states, judging attempted harms as less morally forbidden and more morally permissible (Young *et al.*, 2010*a*).

Finally, insular cortex activation is found during various moral tasks (Moll *et al.*, 2002*b*; Greene *et al.*, 2004; Borg *et al.*, 2008; Kedia *et al.*, 2008; Cooper *et al.*, 2010) and is related to emotional processing (Greene *et al.*, 2004; Kedia *et al.*, 2008), to disgust processing (Moll *et al.*, 2002*b*) and to detecting and processing uncertainty (Cooper *et al.*, 2010). Other studies reported that the insula is more strictly involved in moral processing and sensitive to norm violations implicated in deontological judgement (Huebner *et al.*, 2009): it is activated in the perception of inequity (Hsu *et al.*, 2008) and in care and justice cognition (Caceda *et al.*, 2011).

In conclusion, available findings in healthy subjects imply that, although not necessarily engaged in moral decisions, the insular cortex is involved in emotional processing and in encoding inequity. The anterior/middle temporal gyrus has a secondary role, being recruited during working memory and general cognitive processing. Whereas the superior temporal sulcus

evaluates the intentionality and social complexity of moral actions, the temporo-parietal junction has a role in belief attributions and theory of mind, two basic requirements for moral processing.

Patients

The first observation about the temporal lobe's role in moral and violent behaviour comes from psychosurgery. In 1891, Burckhardt removed the temporal lobe in five patients with intractable psychiatric disturbances who he described as demented and aggressive, with unsuccessful results (Berrios, 1997). Temporal lobe resection is a surgical procedure also used to treat patients with temporal lobe epilepsy, who often experience psychiatric, cognitive and behavioural manifestations (Hamberger and Drake, 2006; Schramm, 2008; David *et al.*, 2009). This procedure is able to solve behavioural disorders, although patients continue to experience cognitive disturbances involving memory and language. Although no studies have specifically investigated moral decisions in patients with temporal lobe epilepsy and in patients who underwent temporal lobe resection, their behavioural abnormalities could at least partly reflect damage to limbic structures, in particular the amygdala. Anatomical studies showed reduced temporal

lobe volume in patients with early-onset conduct disorder (Kruesi et al., 2004), in incarcerated psychopaths (Dolan et al., 2002) and in antisocial personality disorders (Barkataki et al., 2006). In line with anatomical observations, neuroimaging studies documented reduced temporal lobe activation in aggressive patients (Volkow and Tancredi, 1987; Amen et al., 1996), psychopaths (Soderstrom et al., 2000) and violent offenders (Raine et al., 2001). Electro-encephalographic recordings also disclose right temporal lobe abnormalities in patients with aggressive antisocial behaviour (David et al., 2009).

Structural abnormalities and volume losses in the right superior temporal gyrus have been reported in psychopathic individuals (Müller et al., 2007 cited in Weber et al., 2008). Activation deficits in this brain area are reported in antisocial and psychopathic patients during a semantic processing task, showing that psychopaths used more cognitive resources to process affective information than did healthy subjects (Kiehl et al., 2004).

Reduced bilateral activation in the middle temporal gyrus is also a typical neuroimaging finding in aggressive children with temporal lobe epilepsy (Juhasz et al., 2001), antisocial patients (Goethals et al., 2005), violent psychiatric patients (Volkow et al., 1995) and violent offenders (Seidenwurm et al., 1997; Soderstrom et al., 2000).

Reduced activation is reported also in the anterior temporal cortex in violent patients (Wong et al., 1997) and in psychopaths during a moral decision-making task (Fig. 1) (Harenski et al., 2010). Anterior temporal lobe involvement in psychopaths seems to be related specifically to reduced ability to process morally salient stimuli, restricting moral processing to generation of semantic and emotional context (Harenski et al., 2010).

Among temporal structures, the hippocampus has an important role in emotion and behaviour. A significant negative correlation was found between the posterior hippocampal volume and degree of psychopathology in repetitive violent offenders (Laakso et al., 2001), and a specific abnormal hippocampal morphology in the absence of total grey matter volume changes characterizes habitually violent offenders (Boccardi et al., 2010). These data fit well with the hippocampal role in the acquisition and retrieval of fear conditioning (Burman et al., 2006; Tsetsenis et al., 2007), and in aggressive and impulsive behaviour (Guillot et al., 1994; Sluyter et al., 1996; Deakin, 2003; Prior et al., 2004; Cardinal, 2006; van Goozen and Fairchild, 2006). Last, hippocampal stimulation in humans elicits severe rage reactions (Heath, 1992). Using depth electrodes in patients with epilepsy with aggressive behaviour, Saint-Hilaire et al. (1981) recorded epileptic activity localized to the right hippocampus during a spontaneous aggression.

Finally, ictal electroencephalographic recordings in aggressive patients with temporal seizures show that the epileptic activity during spontaneous epileptic aggressive behaviour localizes first in the right amygdala, then in the right temporal cortex, right hippocampus and parahippocampal gyrus and then reaches the anterior and median cingulate gyrus and right supplementary motor area (Saint-Hilaire et al., 1981).

Right insular lesions are associated with low emotional intelligence, poor judgement in decision-making and disturbances in social functioning (Bar-On et al., 2003). Bilateral grey matter reduction in the insula are reported in psychopaths (de Oliveira-Souza et al., 2008). Fear conditioning activates insula in healthy subjects but not in psychopaths (Birbaumer et al., 2005), suggesting that the emotional processing for anticipated pain and for threat stimuli is impaired in patients.

In conclusion, studies from patients argue that various temporal areas, in particular the superior temporal gyrus, the middle temporal gyrus and the anterior temporal cortex, are closely related to moral judgements and violent behaviour. The hippocampus is consistently associated with violent–aggressive behaviour and is involved in the development of moral constitution (Laakso et al., 2001).

Parietal lobe

Healthy subjects

Some functional neuroimaging studies report inferior parietal lobe activation during moral processing (Greene et al., 2004; Harenski et al., 2008; Caceda et al., 2011). The study by Greene et al. (2004) suggests that this brain area is associated with working memory and cognitive control, so that it is recruited because the task proposed engaged cognitive processing.

Patients

Whereas, to our knowledge, no published data are available on parietal lesions or abnormalities and moral behaviour, neuroimaging studies disclose increased blood flow in the parietal cortex in non-psychotic violent offenders (Soderstrom et al., 2000). In murderers (Raine et al., 1997) and individuals with impulsive personality disorders (Siever et al., 1999) metabolism—investigated using functional MRI and PET—was reduced in the superior parietal cortex.

In conclusion, despite the scant literature, although available data argue that the parietal lobe contributes to moral judgement and is involved in abnormal moral behaviour, its precise function in processing moral decisions is still unknown.

Subcortical structures

Healthy subjects

Only few functional MRI studies have found subcortical involvement during moral processing. The amygdala activates during processing of both basic and moral emotions (Moll et al., 2002b), during evaluation of moral judgement (Greene et al., 2004), during violation of severity ratings for moral pictures (Harenski et al., 2008) and during personal desire-oriented decisions in contrast to morally guided responses (Sommer et al., 2010). Amygdala activation is reduced during passive viewing of moral and non-moral pictures when individuals attempted to decrease emotions (Harenski and Hamann, 2006) and in response to bodily harm (Heekeren et al., 2005). Amygdala activation induced by bodily harm may reflect amygdala-specific involvement in affective judgements about the emotional value of an action

(Heekeren *et al.*, 2005), and could imply reduced moral brakes when the individual is in danger.

Bilateral thalamic activation can be observed during decisions on whether to follow a moral rule or fulfil a personal desire (Sommer *et al.*, 2010), whereas activation in the septal region is related to charitable donations (Moll *et al.*, 2006).

The caudate nucleus is activated during the evaluation of moral stimuli (Luo *et al.*, 2006), in charitable living (Harbaugh *et al.*, 2007) and in altruistic punishment (de Quervain *et al.*, 2004).

The amygdala therefore appears to be a pivotal subcortical structure involved in processing moral emotions.

Patients

Evidence that subcortical structures intervene in morality is further supported by data from patients. Disinhibition and violent behaviour are related to grey matter loss or volume loss or structural amygdala abnormalities in violent offenders (Wong *et al.*, 1997; Tiihonen *et al.*, 2000; Van Elst *et al.*, 2000) and in psychopathic individuals (Yang *et al.*, 2006). Why amygdalotomy improves 30–40% of patients with severe behavioural disturbances, aggressiveness and violent behaviour (Fountas and Smith, 2007) therefore remains unclear. A possible explanation is that amygdala dysfunction causes patients' behavioural abnormalities and aggressiveness. In these instances, surgery to remove dysfunctional amygdala can restore normal behaviour. Neuroimaging studies during various tasks report inconsistent results on amygdala responses: two functional MRI studies reported increased amygdala activation in antisocial individuals viewing negative visual content (Müller *et al.*, 2003) and during an aversive conditioning task (Schneider *et al.*, 2000). In contrast, others report reduced amygdala activation during the processing of negative affective stimuli in criminal psychopaths (Kiehl *et al.*, 2001), in fear conditioning in criminal psychopaths (Veit *et al.*, 2002; Birbaumer *et al.*, 2005), in response to emotional stimuli in adolescents with conduct disorders (Sterzer *et al.*, 2005) and during emotional moral decision-making in psychopathy (Glenn *et al.*, 2009). Another study comparing psychopaths and healthy subjects during a moral decision-making task found that psychopaths lacked a positive association between amygdala activity and the severity of moral violation ratings, suggesting a reduced emotional response (Harenski *et al.*, 2010). Collectively, findings in patients agree with those in healthy subjects and confirm a pivotal role of the amygdala in processing moral emotions. In line with structural and neuroimaging studies, stimulation studies also showed amygdala involvement in emotion and violence expression. Heath *et al.* (1955) described the case of a patient receiving amygdala stimulation who became enraged and attacked the psychiatrist. Some studies in Treiman's (1991) review also reported aggressive behaviour during amygdala stimulation. The amygdala might therefore represent a sort of 'switch' between brain processing of moral emotions and their translation into action and aggression.

Impulsive-antisocial temperament of psychopathic patients is related to neurochemical and functional nucleus accumbens alterations during monetary reward anticipation. The role of this structure in psychopathic behaviour probably reflects its participation in the mesolimbic dopaminergic system, involved in reward and impulsive behaviour (Buckholtz *et al.*, 2010).

Early evidence suggesting the role of the septum in empathy, guilt and remorse in psychopathy (Gorenstein and Newman, 1980) has now been corroborated by a PET study reporting hypometabolism in the septal region while patients with the behavioural variant of frontotemporal dementia executed a moral sentiment task (Moll *et al.*, 2011).

Accidental stimulation of the posteromedial hypothalamic area by deep brain stimulation induced aggressive behaviour in patients with Parkinson's disease (Bejjani *et al.*, 2002; Sensi *et al.*, 2004). In contrast, deep brain stimulation of the posterior hypothalamus improved patients with disruptive behaviour and mental retardation (Franzini *et al.*, 2005; Hernando *et al.*, 2008; Kuhn *et al.*, 2008).

In patients with Parkinson's disease, subthalamic nucleus deep brain stimulation can occasionally induce mild personality changes, disinhibition, mood changes, hypersexuality and pathological gambling (Temel *et al.*, 2005), ultimately influencing moral behaviour. Neurophysiological studies over the past 10 years have described subthalamic activity changes in local field potentials recorded through the stimulation electrodes implanted for deep brain stimulation in patients with Parkinson's disease engaged in various cognitive and behavioural tasks (Kuhn *et al.*, 2005; Brucke *et al.*, 2007; Marceglia *et al.*, 2009, 2011; Fumagalli *et al.*, 2011). In a study conducted in our laboratory to assess the role of basal ganglia in moral decision-making and in the processing of moral conflictual stimuli (Fumagalli *et al.*, 2011), we recorded subthalamic local field potentials from 16 Parkinsonian patients doing a moral task. The task required patients to evaluate moral conflictual, moral non-conflictual and neutral sentences, and to respond if they agreed or disagreed by pressing one of two buttons. The results showed that a specific subthalamic rhythm, low-frequency band (5–13 Hz), is involved in decision processing: the subthalamic nucleus intervenes in moral judgement in a conflict-dependent way, its oscillations being specifically modulated by moral conflictual stimuli. These findings extend the 'moral brain' to encompass the basal ganglia including the subthalamic nucleus, especially for conflict processing (Fumagalli *et al.*, 2011) (Fig. 2).

In summary, available data argue for subcortical participation in the brain network responsible for moral reasoning. The amygdala has a crucial role in processing social and emotional content and in particular in learning that some actions harm others and should therefore be avoided (Blair, 2007). Amygdala structural and functional impairments mean that psychopathic individuals and criminals are unable to recognize cues that signal threat, becoming relatively fearless and more readily engaged in antisocial behaviour (Sterzer, 2010). Finally, the septal area is involved in empathy and altruism and its hypometabolism is associated with impairments on prosocial sentiments, such as pity and guilt (Moll *et al.*, 2011). Emerging evidence suggesting that subcortical structures intervene in abnormal moral behaviour might indicate directions for future research on the therapeutic effects of deep brain stimulation in psychopathic disorder and violent behaviour.
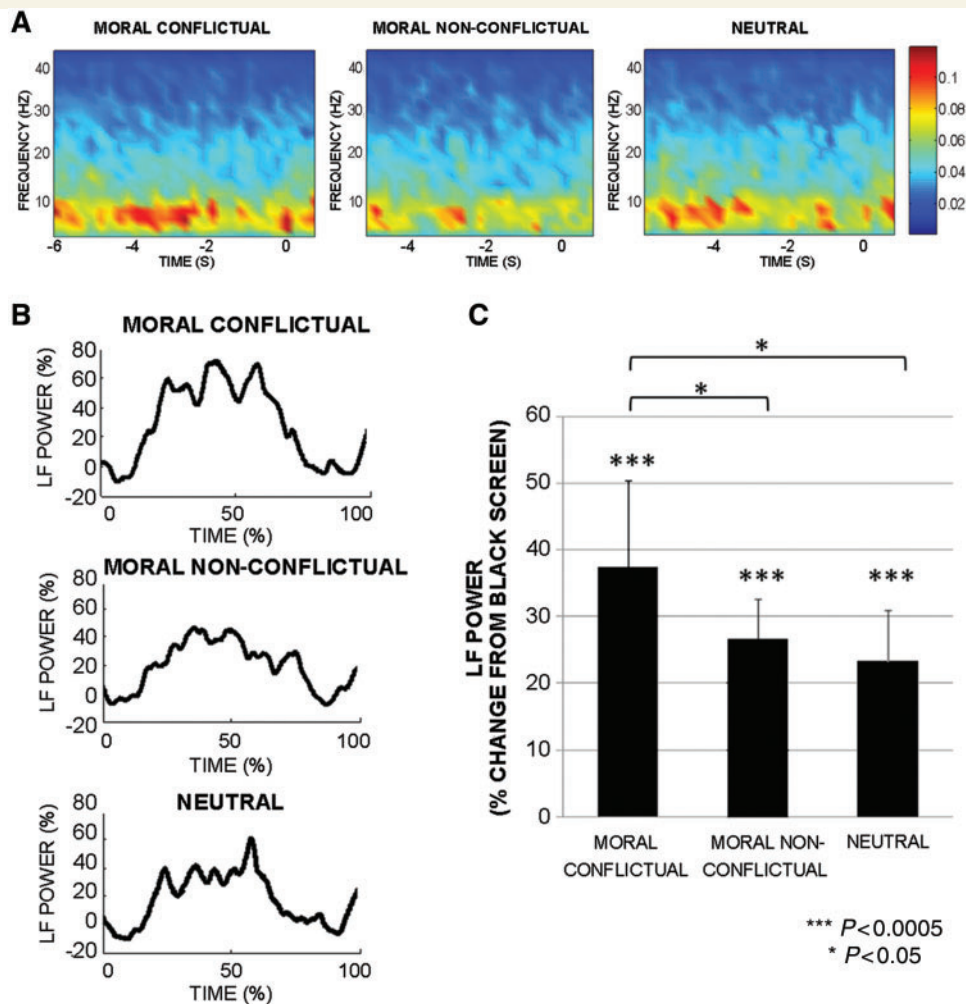
Figure 2 Subthalamic local field potentials in patients with Parkinson's disease during a moral decision task. (**A**) Time–frequency plots of grand average subthalamic nucleus local field potentials in each task condition (moral conflictual, moral non-conflictual, neutral). The x-axis shows the time (s) from the mean reaction time value of the task condition to 1 s after the choice. The sentence evaluation phase starts from sentence presentation to 500 ms before key pressing (time = 0). Note that during the moral task, low-frequency power (5-13 Hz) increased during sentence evaluation. (**B**) Low-frequency (LF) power modulation during the sentence evaluation for each task condition shows higher modulation during moral conflictual sentences. (**C**) Histograms represent the mean low-frequency modulation in sentence evaluation during each task condition. Note the significantly higher power modulation during the moral conflictual condition. In conclusion, subthalamic local field potential recordings show strong subthalamic nucleus activation especially during conflictual moral decisions. Error bars represent the confidence interval of the estimated mean (1.96 × standard error). (Reprinted from Fumagalli *et al.*, 2011, with kind permission of Taylor & Francis Ltd. http://www.informaworld.com).

Genes and hormones

Two centuries ago, the Italian criminologist Cesare Lombroso suggested that phenotypic features revealed the criminal attitude of the individual. The general concept that genetic alterations, abnormalities in the brain and its functioning can be linked to criminal behaviour nowadays attracts interest (Pietrini and Bambini, 2009). Geneticists have shown that complex behavioural disorders can partly arise from variations in DNA sequences and environmental factors. Family, twin and adoption studies have all suggested that genetic factors contribute to antisocial personality disorders and externalizing behaviours. Genetic and non-shared environmental factors are both important in the development of psychopathy. The weight of the two factors is debated, but increasing evidence shows that genetic factors account for 49–81% of the variance and in psychopathy are more important than environment (Gunter *et al.*, 2010).

The brain catecholaminergic systems regulate aggressive behaviour. Two major enzymes are responsible for catecholamine catabolism in the brain: monoamine oxidase A (MAOA) and catechol-*O*-methyltransferase (COMT). The MAOA gene is located on the X chromosome. The MAOA enzyme preferentially catabolizes the brain neurotransmitters noradrenaline and serotonin (Volavka *et al.*, 2004). The remarkable consequences of MAOA gene deletions in mice suggest that mild functional variations in this gene probably have significant behavioural impacts
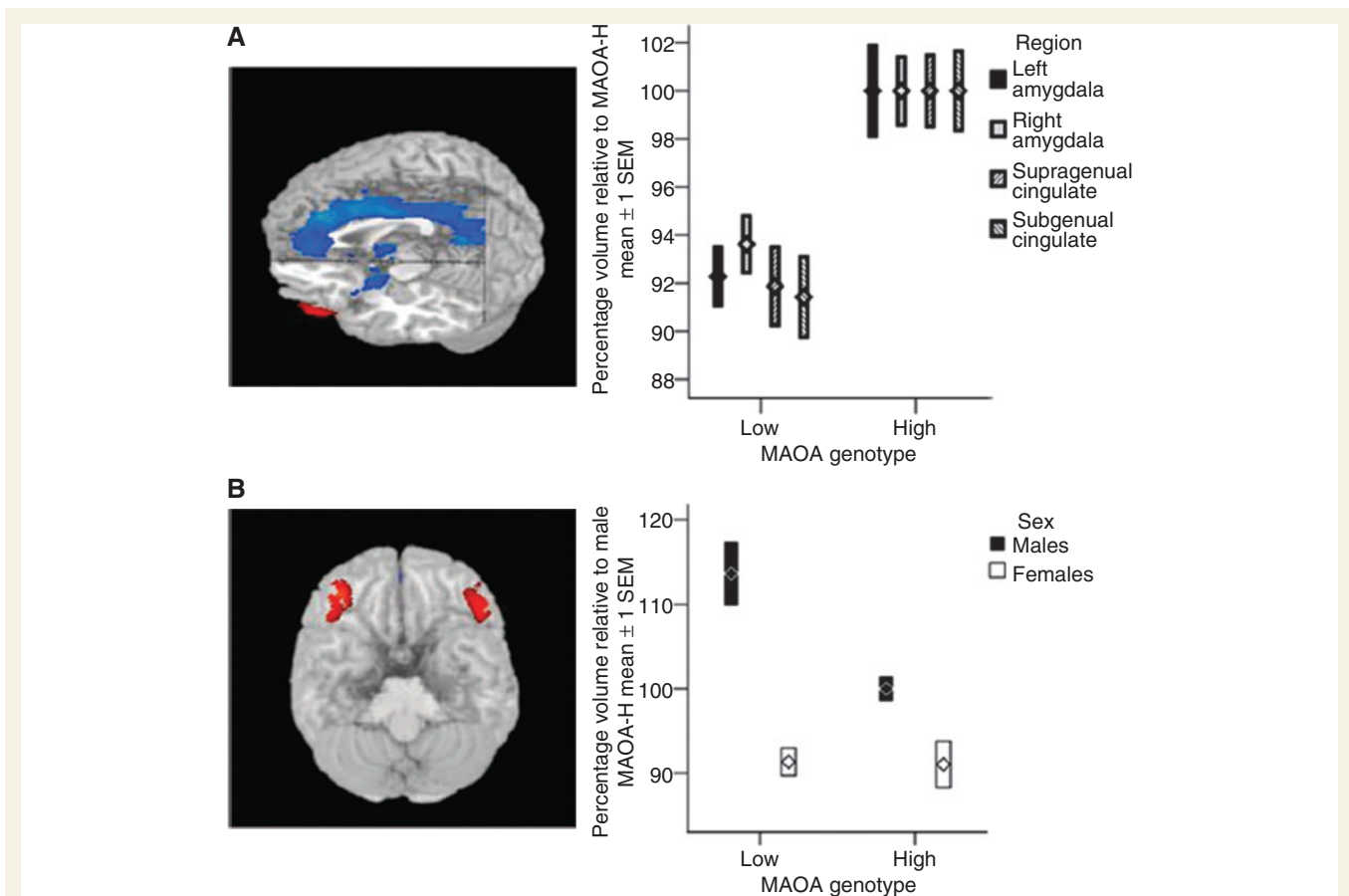
Figure 3 The correlation between the MAOA polymorphism and brain structure and function assessed with MRI in healthy humans. (**A**) Individuals with the low-expression variant associated with an increased risk of violent behaviour compared with subjects with the high-expression variant exhibit significant volume reductions in bilateral amygdala, supragenual anterior cingulate and subgenual anterior cingulate cortex. (**B**) Male individuals with the low-expression variant show greater lateral orbitofrontal volume, bilaterally, than subjects with the high-expression variant. No genotype effect was found in females, indicating a highly significant sex × genotype interaction. Plots represent the summed volumes of voxels in predefined region of interest, normalized to volume measures relative to the high-expression variant of the MAOA gene (MAOA-H) group mean (100%). [Reprinted from Meyer-Lindenberg *et al.*, 2006, with kind permission of National Academy of Sciences, USA—Copyright (2011) National Academy of Sciences, USA].

(Shih *et al.*, 1999). In humans, the first proof of a link between aggressivity and MAOA came from a study investigating a Dutch family with a repeated incidence of violent criminal behaviour among males across several generations all of whom had a MAOA gene abnormality (Brunner *et al.*, 1993). Low MAOA activity, combined with traumatic early life events, seems to increase the likelihood of antisocial disturbances in adults (Caspi *et al.*, 2002; Meyer-Lindenberg *et al.*, 2006; McDermott *et al.*, 2009) (Fig. 3). Low enzymatic COMT activity is associated with increased brain catecholamine levels that raised the likelihood of aggression (Volavka *et al.*, 2004). Consistent with this expectation, COMT knockout mice exhibited increased aggressive behaviour (Gogos *et al.*, 1998) and in humans, the COMT Met allele is associated with aggressive behaviour in males (Craig and Halton, 2009).

As well as genetic factors, hormones can profoundly influence behaviour and cognition by interfering with brain metabolism and neuronal function. Areas implicated in social and emotional processing have extensive connections with peripheral physiological functioning, and specifically, have strong reciprocal connections

with the endocrine system. Whereas the hypothalamus–pituitary–gonadal axis is involved in the reproductive and immune systems (Terburg *et al.*, 2009), the hypothalamic–pituitary–adrenal axis is entailed in the limbic emotion-related neurocircuitry. The end product of the hypothalamic–pituitary–adrenal axis is cortisol and the end product of the hypothalamus–pituitary–gonadal axis is testosterone. Cortisol is a key modulator of several emotion-related learning and memory processes, of social behaviour, and is also associated with anxiety symptoms. The brain network involved in cortisol regulation includes the prefrontal cortex, insula, amygdala and anterior cingulate cortex. In particular, the prefrontal cortex is implicated in hypothalamic–pituitary–adrenal axis inhibition and regulation and insular activity in response to traumatic stimuli is associated with adrenocorticotropic hormone responsivity (Shirtcliff *et al.*, 2009). Finally, anterior cingulate cortex hypoactivation indicates reduced cortisol reactivity and is associated with callousness (Shirtcliff *et al.*, 2009), whereas hyper-activation means increased cortisol reactivity and is related to social stressors (Eisenberger *et al.*, 2007). Extensive behavioural

endocrinology research associated reduced hypothalamic–pituitary–adrenal axis functioning in children and adolescents with the development of psychopathy (van Honk and Schutter, 2006). Lower cortisol levels characterize psychopathic patients (Holi *et al.*, 2006; O'Leary *et al.*, 2007; Cima *et al.*, 2008), patients with antisocial disorder with limited empathy and guilt and constricted emotionality (Hawes *et al.*, 2009), and adolescents with conduct disorder (Cappadocia *et al.*, 2009; Victoroff, 2009).

Another hormone involved in aggressive behaviour is testosterone. High testosterone levels enhance attention to aggressive stimuli, downregulate the interaction between cognitive and emotional brain systems and are associated with dominant aggressive behaviour (Dabbs *et al.*, 1995; Dabbs and Hargrove, 1997). During moral decision-making, individuals having high testosterone levels are more likely to make utilitarian decisions, especially when doing so implies acts of aggression and social cost (Carney and Mason, 2010). Testosterone is also associated with diminished sensitivity to the affective signals that facilitate pursuit of empathic behaviours and choices (van Honk *et al.*, 2004, 2005, 2010). Although the gender factor is largely ignored in neuroimaging and lesional studies on morality, testosterone might partially explain the gender differences highlighted by previous behavioural studies (Gilligan, 1982; Jaffee and Hyde, 2000).

Finally, because a heightened testosterone level alone is often not enough to induce violence (Terburg *et al.*, 2009), the hormonal marker for aggressive behaviour is the testosterone/cortisol ratio. When high testosterone is combined with low cortisol,

aggression is unmanageable and the subject could become a danger to society (Terburg *et al.*, 2009; van Honk *et al.*, 2010).

We found no studies investigating the correlation between the performances in a moral task with either COMT/MAOA genetic polymorphism or testosterone/cortisol levels in healthy subjects, although this could be an interesting issue for future research. Another possible shortcoming worth investigating is that these studies measured basal hormone concentrations, without considering receptor site functioning, possible interactions with other hormones and the mechanisms that regulate protein transcription and hormone secretion, all factors that can ultimately influence the behavioural effects of a given hormone, independently from its concentrations (Carney and Mason, 2010).

An overall view

As well as depending on the various underlying cortical areas, moral functions and abnormal moral behaviour depend on a distributed functional neural network connecting cortical and subcortical structures (Fig. 4 and Table 1), modulated by neurotransmitters and hormonal systems. Recent behavioural evidence showing abnormal moral reasoning in patients with callosotomy also suggest that this neural network is not confined to one side of the brain (Miller *et al.*, 2010). Because morality is a complex process, some of the brain structures involved share their neural circuits with those controlling other behavioural processes, such as
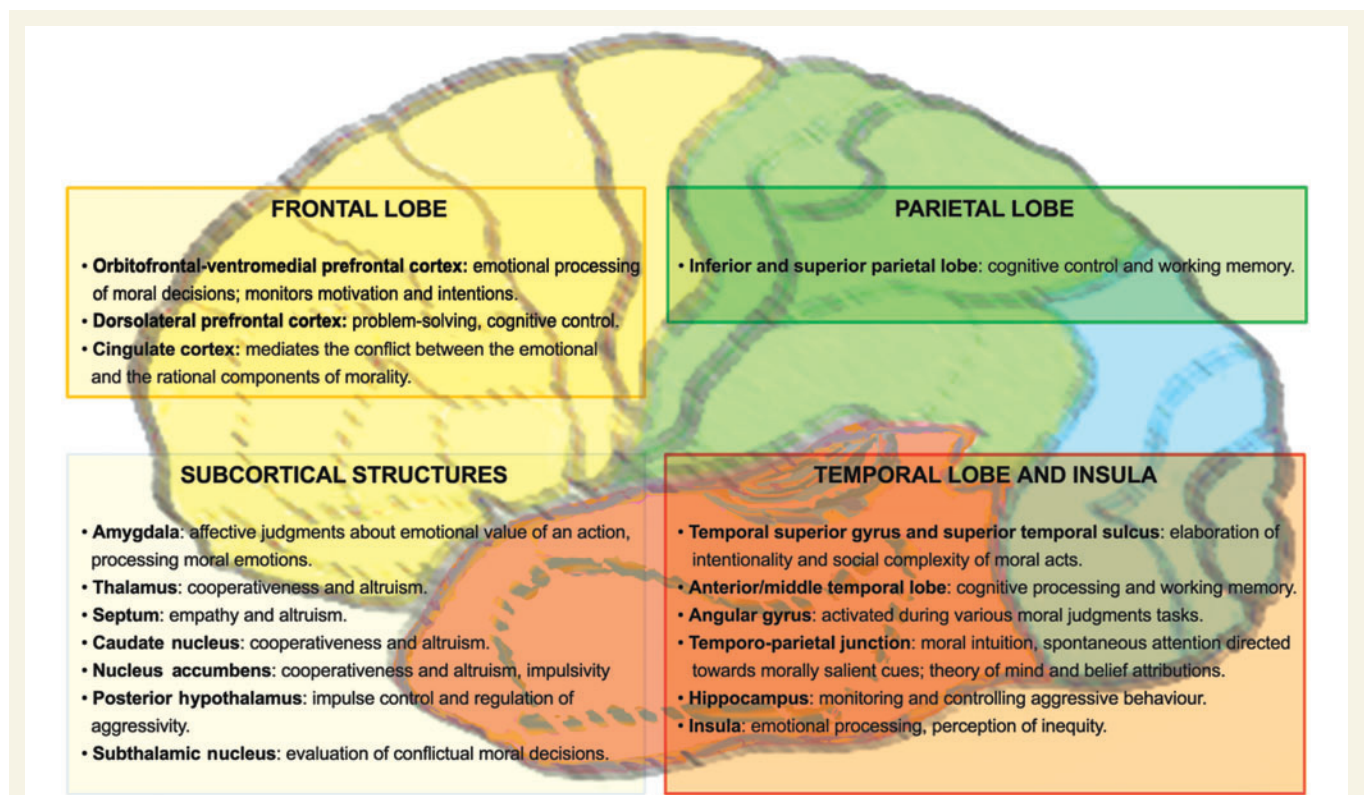

Figure 4 A schematic diagram reporting the hypothetical role of various brain areas in regulating moral behaviour.

Table 1 List of studies subdivided according to brain area and type of study

Brain structure	Evidence from	References
Frontal lobe		
Frontopolar cortex	Lesional studies	Eslinger et al., 1992; Anderson et al., 1999
Orbitofrontal cortex—ventromedial prefrontal cortex	Studies in healthy subjects	Rolls, 2000; Greene et al., 2001; Moll et al., 2001, 2002a, b, 2005; Heekeren et al., 2003; Borg et al., 2006; Harenski and Hamann, 2006; Luo et al., 2006; Prehn et al., 2008; Harenski et al., 2009; Young and Saxe, 2009; Cooper et al., 2010; Fumagalli et al., 2010; Shenhav and Greene, 2010; Sommer et al., 2010
	Psychopathy and antisocial behaviour	Goyer et al., 1994; Raine et al., 1994, 2000; Bufkin and Luttrell, 2005; Yang et al., 2005; Harenski et al., 2009, 2010
	Lesional studies	Damasio et al., 1990; Saver and Damasio, 1991; Eslinger et al., 1992; Rolls et al., 1994; Grafman et al., 1996; Anderson et al., 1999; Brower and Price, 2001; Ciaramelli et al., 2007; Koenigs et al., 2007; Braun et al., 2008; Feuchtwanger, 1923 (cited in David et al., 2009); Moretto et al., 2009; Thomas et al., 2011; Young et al., 2010b
	Frontotemporal dementia	Moll et al., 2011
	Epilepsy	Woermann et al., 2000
Dorsolateral prefrontal cortex	Studies in healthy subjects	Greene et al., 2001, 2004; Haushofer and Fehr, 2008; Prehn et al., 2008; Greene and Paxton, 2009
Cingulate cortex	Studies in healthy subjects	Greene et al., 2001, 2004; Harenski et al., 2008
Temporal lobe		
Temporal lobe	Lesional studies	David et al., 2009
	Psychopathy and antisocial behaviour	Volkow and Tancredi, 1987; Amen et al., 1996; Soderstrom et al., 2000; Raine et al., 2001; Dolan et al., 2002; Kruesi et al., 2004; Barkataki et al., 2006; David et al., 2009
	Epilepsy	Saint-Hilaire et al., 1981
Anterior/middle temporal lobe	Studies in healthy subjects	Moll et al., 2001; Heekeren et al., 2003, 2005; Greene et al., 2004; Harenski and Hamann, 2006; Sommer et al., 2010
	Psychopathy and antisocial behaviour	Volkow et al., 1995; Seidenwurm et al., 1997; Wong et al., 1997; Soderstrom et al., 2000; Goethals et al., 2005; Harenski et al., 2010
	Epilepsy	Juhasz et al., 2001
Superior temporal sulcus	Studies in healthy subjects	Moll et al., 2001, 2002a, b; Heekeren et al., 2003, 2005; Greene et al., 2004; Borg et al., 2006; Harenski and Hamann, 2006
Superior temporal gyrus	Psychopathy and antisocial behaviour	Kiehl et al., 2004; Müller et al., 2007 (cited in Weber et al., 2008)
Temporo-parietal junction	Studies in healthy subjects	Young et al., 2007, 2010a; Kedia et al., 2008; Harenski et al., 2009; Young and Saxe, 2009; Young and Dungan, 2011
Angular gyrus	Studies in healthy subjects	Greene et al., 2001; Borg et al., 2006
Insula	Studies in healthy subjects	Moll et al., 2002b; Greene et al., 2004; Borg et al., 2008; Hsu et al., 2008; Kedia et al., 2008; Cooper et al., 2010; Caceda et al., 2011
	Psychopathy and antisocial behaviour	Birbaumer et al., 2005; de Oliveira-Souza et al., 2008
Hippocampus	Psychopathy and antisocial behaviour	Laakso et al., 2001; Boccardi et al., 2010
	Epilepsy	Saint-Hilaire et al., 1981
Parietal lobe		
Parietal cortex	Psychopathy and antisocial behaviour	Soderstrom et al., 2000
Inferior parietal lobe	Studies in healthy subjects	Greene et al., 2001, 2004; Harenski et al., 2008; Caceda et al., 2011
Superior parietal cortex	Psychopathy and antisocial behaviour	Raine et al., 1997; Siever et al., 1999
Subcortical structures		
Amygdala	Studies in healthy subjects	Moll et al., 2002b; Greene et al., 2004; Heekeren et al., 2005; Harenski and Hamann, 2006; Harenski et al., 2008; Sommer et al., 2010
	Psychopathy and antisocial behaviour	Wong et al., 1997; Schneider et al., 2000; Tiihonen et al., 2000; Van Elst et al., 2000; Kiehl et al., 2001; Veit et al., 2002; Müller et al., 2003; Birbaumer et al., 2005; Sterzer et al., 2005; Yang et al., 2006; Fountas and Smith, 2007; Glenn et al., 2009; Harenski et al., 2010
	Stimulation	Heath et al., 1955; Treiman, 1991
Septum	Studies in healthy subjects	Moll et al., 2006
	Frontotemporal dementia	Moll et al., 2011
	Psychopathy and antisocial behaviour	Gorenstein and Newman, 1980
Caudate nucleus	Studies in healthy subjects	de Quervain et al., 2004; Luo et al., 2006; Harbaugh et al., 2007
Nucleus accumbens	Psychopathy and antisocial behaviour	Buckholtz et al., 2010
Subthalamic nucleus	Deep brain stimulation studies	Fumagalli et al., 2011
Thalamus	Studies in healthy subjects	Sommer et al., 2010
Posterior hypothalamus	Deep brain stimulation studies	Bejjani et al., 2002; Sensi et al., 2004; Franzini et al., 2005; Hernando et al., 2008; Kuhn et al., 2008

emotions and theory of mind. Overall, findings from healthy subjects and patients show that the anatomical structures implicated in morality are the frontal and temporal cortices and specific subcortical structures. The frontal lobe, in particular the orbital and ventromedial prefrontal cortices, has a primary role in moral behaviour, emotionally driving moral decisions and being involved in abnormal moral behaviour. The temporal lobe intervenes in moral decisions through its role in intentionality and social complexity of moral decisions (superior temporal sulcus), belief attributions and theory of mind (temporo-parietal junction), and is often associated with aggressive behaviour in violent patients and criminals. Among subcortical structures, the amygdala is of major importance in processing moral emotions and when damaged or dysfunctional, leads to violence. Finally, subcortical involvement in abnormal moral behaviour might advance research on the therapeutic effects of deep brain stimulation in psychopathy and violent behaviour.

Limitations

Moral neuroscience is an extremely wide and rapidly expanding field. In this review, we synthetically outline only the major research findings. Despite this limitation, our review should provide to the clinical neuroscientist a useful tool for approaching the complex biology of moral behaviour.

Among limitations to keep in mind in planning further experimental work, an initial problem is that the widely varying tasks used for assessing morality make the various results difficult to compare. Moral tasks also have intrinsic limitations. For example, most tasks fail to take an ecological approach (the items proposed poorly reflect environmental and daily experience). Some tasks also require subjects to evaluate abstract judgements excluding the complex context in which the decision has to be taken. Third, task instructions tell the subject not to make additional assumptions not included in the text, even though problem-solving is a faculty that automatically intervenes in these situations. And, equally important, moral items distinctly differ one from the other and involve various moral rules, values (honesty, money, life, health, probity, solidarity) and violations.

Another limitation concerns the failure to balance the study sample for gender. Gender is a major problem that studies on morality need to take into account (Harenski *et al.*, 2008; Fumagalli *et al.*, 2010). Studies on patients often enrol too few subjects, usually owing to the strict diagnostic criteria required to select those with a disease or brain lesion. Studies on patients with lesions also need careful interpretation owing to the remarkable heterogeneity (volume, shape, date of onset, concurrent treatments) in spontaneous lesions. This heterogeneity can sometimes make it difficult to pool data from different patients. Finally, because morality is a complex process, influenced by social and cultural factors, future studies should also consider age, education and religious beliefs.

areas and circuits mediating normal and abnormal moral behaviour, future research, taking into consideration the foregoing limitations, should aim to find out how human moral behaviour is influenced by genetic, endocrine, environmental and cultural factors.

Understanding the 'moral brain' and its behavioural counterpart raises several potentially important legal and clinical implications. Ruling that criminals whose abnormal moral behaviour depends on biological anomalies cannot be held fully responsible for their criminal actions, an Italian court lightened a sentence for a convicted murderer because tests identified genes linked to violent behaviour (Feresin, 2009). The enormous advances neurosciences have achieved over the past decades should therefore help to update the criteria and protocols for deciding whether the criminal brain is normal. Forensic neurosciences now have major importance (Bianchi *et al.*, 2009) and neurologists could have increasing weight as court advisors.

From a clinical point of view, subjects manifesting abnormal moral behaviour should be screened for neurological disorders to promote an early diagnosis. A potentially important issue arises when clinicians treat patients whose social position makes them responsible for others (including state leaders and politicians) with abnormalities of moral behaviour or with other conditions (or treatment) that could influence their 'moral brain'. In these cases, an early diagnosis and, whenever possible, effective treatment are important both for the patient and for the welfare of society. Highlighting the social importance of early diagnosis and treatment, David Owen (2008) described in his book 'In Sickness and in Power' several cases of leaders responsible for states and nations who took important political decisions whilst suffering from various medical conditions and discussed how the disease or drugs taken could have influenced the decision itself possibly even in its moral aspects. Hence, recognizing acquired abnormalities in moral decision-making raises intriguing concerns in clinical practice. For instance, should moral reasoning be formally evaluated after a minor stroke without overt cognitive and motor sequelae, or during any medical treatment with drugs acting on the brain? Last, understanding the dysfunctional brain structures underlying abnormal moral behaviour can lead to specific treatments nowadays using deep brain stimulation or other new non-invasive neuromodulation techniques. For instance, apart from treating aggression, deep brain stimulation might be used in other forms of pathological antisocial behaviour or violence (including sexual assaulters and paedophiles) when education and rehabilitation programmes or other treatments fail. Among future concerns about the hypothetical use of brain stimulation techniques in this field, the possibility of shaping individual morality raises intriguing ethical issues that should prompt the development of treatment guidelines.

Concluding remarks

The findings our review provides on the functional and clinical neuroanatomy of morality argue strongly that a brain network for moral behaviour exists. As well as investigating the brain

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