# Forensic neurosciences: from basic research to applications and pitfalls

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**Purpose of review**

In recent years, there has been growing interest in the application of genetic and neuroscientific methods to the investigation of the criminal mind. Here we summarize the results of recent studies and discuss their potential implications for the criminal system.

**Recent findings**

The results of studies published so far have implications for theoretical aspects of the law. For example, a series of studies have indicated that conscious sense of volition may not be a driving force in the initiation of willed behavior but rather may arise as a consequence of such behavior. According to some, this challenges the very notion of conscious will on which the criminal system is based. The results also have implications for practical aspects of the law. For instance, genetic and neuroscientific methods may provide objective, biological data which can be used to reduce controversy in forensic psychiatric evaluations of mental insanity and minimize errors in detecting malingering. Another potential practical application is lie and memory detection, which at present appears to be susceptible to countermeasures.

**Summary**

Genetic and neuroimaging techniques may provide information which, when considered in combination with other sources of evidence, might prove useful in advancing knowledge about *mens rea.*

**Keywords**

criminal system, genetics, law, neuroscience

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## Introduction

Deviant behavior, which can be defined as a violation of cultural norms and/or enacted law, is a crucial matter for worldwide societies. In recent years, developments in behavioral genetics and cognitive neuroscience have allowed the scientific investigation of the biological basis of a number of cognitive processes which are relevant to deviant behavior. These include conscious will, impulse control, decision-making, emotional regulation, empathy and malingering. The results of the studies published so far have potential implications for theoretical aspects of the law; for example, according to some, studies on the neural basis of free will challenge the current notion of legal responsibility on which the criminal system is based. The results of these studies, however, also have important implications for practical aspects of the law; for instance the observation in adolescents of underdeveloped prefrontal regions involved in decision-making and impulse control has influenced the US Supreme Court decision to ban the death penalty for under-age defendants [1].

Here we focus on a limited number of issues which have attracted much interest amongst scientists and law scholars. As an example of the relevance of neuroscientific methods to theoretical aspects of the law, we will focus on recent advancements in the study of conscious (free) will. We will then summarize the most recent findings of genetic and neuroimaging studies of aggressive behavior and discuss how this information could be used in a forensic setting. Finally we will present the results of recent studies of lie detection and consider the feasibility of using neuroscientific techniques to detect malingering.

## Neuroscience and theoretical aspects of law (free will)

The purpose of criminal law can be defined as the detection and prosecution of malicious action. It is assumed that the defendant has free will and is the original cause of their behavior. This basic assumption, however, appears to be challenged at some level by the results of neuroscientific studies of free will. Traditionally the investigation of free will has been conducted in philosophical and speculative terms but, in recent years, a number of studies have attempted a scientific investigation of the neurocognitive mechanisms underlying what philosophers and legal scholars call 'free will'. The definition of free will typically used by neuroscientists can be approximated as 'feeling of having a free will' or the 'perception of volition' [2]; it should be stressed that this definition represents only one of a number of alternative philosophical and legal definitions of free will. To date neuroscientific investigations have provided insight into the relationship between brain mechanisms involved in our subjective experience of conscious and voluntary decisions [3–7]. In Libet's experiment [3], for example, individuals were sat in front of a clock with a rapidly moving spot and were instructed to move their index finger at will. Subsequently, they were asked to report where the spot was (from which the precise timing was derived) when they were first aware of their intention to act. The critical finding was that individuals' awareness of their volition to act was preceded by a slow negative-going potential named the readiness potential that occurred 300–800 ms before. Thus conscious will appeared to come after the ultimate initiation of the act [3]. This finding, which has been replicated in several independent studies [4,6], suggests that the sense of volition may not be a driving force in the initiation of our elementary willed behavior. Rather, it seems that the subjective experience of free will is a construction, derived from the brain's motor system producing a movement and somehow 'informing' consciousness of the movement, with the effect that we feel as if the action has been freely initiated [2,8,9]. This interpretation is supported by a recent investigation [10] which showed that the critical cue for judgment of intention is the perception of the response. The researchers used a variant of Libet's task [3] in which they presented participants with a delayed keyboard click to create the illusion that their response was later than it actually was. A delay in the perceived time of the action resulted in a delay in the reported time of conscious intention, suggesting that the perceived time of action is a prominent factor in judging the beginning of the intention. Rigoni *et al.* [11••] extended previous findings by showing that the readiness potential is malleable to changes in free will beliefs. Participants were required to read a scientific report arguing against the idea of free will prior to undertaking the Libet task. The results showed that this was effective in reducing, with respect to controls, the readiness potential prior to voluntary finger movement. This suggests that changes in beliefs affect the neural correlates of conscious will.

Philosophical and cognitive investigations of free will have identified four key components of free will: acting for intelligible reasons, genuine source of the action (origination), alternative possibilities, and possibility to do otherwise [12]. It appears that Libet type of tasks are specific to conscious volition in elementary movement and therefore fail to capture the cognitive components of free will as described here. In this respect, an investigation which seems more relevant to the different components of free will was reported by Castiello *et al.* [13]. The experimental task required individuals to grasp an object. The authors report that after the sudden unperceived displacement of the object, individuals adjust their motor behavior to the new position without conscious awareness. This absence of awareness is even more striking if we consider that the result was also replicated when the original object was replaced with a new object during the grasping movement. The individuals adapted the grasping movement without conscious awareness and showed surprise for what they found in their hands [13]. Again this shows how consciousness may arise after the motor act and therefore challenge the very notion of conscious will which underlies the philosophical basis of the criminal systems (however see [14•]).

**Key points**

- The finding that conscious sense of volition may not be a driving force in the initiation of willed behavior challenges the very notion of conscious will on which the criminal system is based.
- The use of genetic and neuroimaging methods cannot change the rationale underlying the determination of criminal liability.
- Genetic and neuroscientific methods may provide objective, biological data which can be used to reduce controversy in forensic psychiatric evaluations of mental insanity.
- The application of neuroscientific methods to lie and memory detection appears to be susceptible to countermeasures.

## Neuroscience and the study of criminal behavior

In recent years, developments in behavioral genetics and cognitive neuroscience have allowed a better understanding of the genetic and neuronal basis of criminal behavior. Below we briefly summarize the most recent findings of genetic and neuroimaging studies of aggressive behavior and discuss how this information could be used in a forensic setting. We will focus on psychopathy, a disorder which selectively affects moral reasoning and emotional processing and results in reduced guilt, reduced empathy and callous and unemotional traits.

### Summary of molecular genetic findings

Behavioral genetic studies are providing evidence that specific genetic polymorphisms may represent risk factors for the development of aggressive behavior and other forms of antisocial personality (see [15] for a meta-analytic review). Molecules with major evidence for their possible involvement in deviant behavior are the serotonin transporter (5HTT, also known as SLC6A4), monoamine oxidase A (MAOA) and catechol-O-methyl-transferase (COMT) (see [16] for a review), all of which are involved in regulating levels of serotonin in the brain. 5HTT collects serotonin from the synaptic clefts [17], whereas MAOA and COMT are key enzymes for serotonin inactivation [18,19]. The promoter regions of *5HTT* and *MAOA* genes contain a VNTR (variable number of tandem repeats) sequence that affects their transcriptional activity [17,20], whereas a val/met substitution at codon 158 of the *COMT* gene reduces its enzyme activity [19]. *MAOA*-linked promoter region (*LPR*), *5HTTLPR* and *COMT* low functional alleles have been all associated to conditions featuring reduced serotoninergic activity like depression, anxiety, aggression and impulsiveness [18,21–28]. A further genetic variant, *HTR2B Q20*∗, which leads to a premature stop codon in the serotonin receptor 2B, a key molecule for serotoninergic neurotransmission, has been shown to be associated with impulsive behavior in a group of Finnish violent offenders [29]. It is important to emphasize that none of these genetic variants exerts its effect deterministically, but rather they act by modulating the impact of environmental factors on behavioral traits. Individuals with the low functional *5HTTLPR* allele, for example, are particularly vulnerable to stressful life events [23], whereas antisocial behavior is more common among male carriers of the low functional *MAOA-LPR* who have experienced maltreatments during childhood [22,24]. In summary, an unfavorable genetic make-up combined with aversive environmental stimuli has been found to increase the risk of becoming a violent offender [30].

## Summary of neuroimaging findings

Structural neuroimaging studies have reported that psychopathy is associated with structural alterations within a distributed network, including volume reductions in the prefrontal cortex, the superior temporal cortex, the amygdala and the posterior hippocampus as well as volume increases in the striatum, the corpus callosum and the uncinate fasciculus (see [31•] for review). These results suggest that structural abnormalities in psychopathy are not limited to regions implicated in emotion and social cognition, such as the amygdala and the superior temporal cortex, but are also evident in the striatum and the hippocampus which play a key role in learning and memory. In addition, functional neuroimaging studies of psychopathy have reported functional alterations within a highly widespread network including all four lobes of the cortex as well as several subcortical structures (see [31•] for review). The results, however, have been inconsistent, with different studies reporting altered activation in different regions and the same region showing hypo-activation in some studies and hyperactivation in other studies. For instance, the amygdala was hypo-activated during fear conditioning [32], moral decision-making [33] and social cooperation [34] but hyperactivated during the viewing of emotionally salient scenes [35]. Nevertheless these studies consistently suggest dysfunction of the amygdala in response to emotional stimuli; such dysfunction may be the neural counterpart of poor performance in neuropsychological tests targeting emotional learning [36]. Taken together, the structural and functional neuroimaging studies published so far have identified the prefrontal cortex, the superior temporal cortex, the amygdala and the striatum as most commonly affected.

## Combining molecular genetics and neuroimaging

The emergence of a new field of research ('imaging genetics') which combines molecular genetics and cognitive neuroscience, has allowed the investigation of how specific genes affect brain development and function to increase susceptibility to different psychiatric disorders and/or violent behavior (see [37] for a review). Individuals with low expressing *5HTTLPR*, for example, display a reduced volume of both the amygdala and the perigenual anterior cingulate cortex together with lower functional and anatomical connectivity between these regions [38,39]. Similarly, male carriers of low functional *MAOA-LPR* show reduced volume of both the amygdala and the anterior cingulate cortex [30] with increased functional coupling between the ventromedial prefrontal cortex and the amygdala [40]. The gene-to-brain-to-behavior approach may eventually allow a better understanding of the crime-related behavior in each individual case [41••].

## Application of genetic and neuroimaging findings in the forensic setting

What is the potential application of the above genetic and neuroscientific data in a forensic setting? The criteria for evaluating criminal responsibility are based on the individual's ability to make a distinction between right and wrong and to counter impulse; such abilities are absent in some psychiatric disorders resulting in exemption or a more lenient sentencing. However, psychiatric assessment of many mental disorders has low inter-rater concordance particularly with respect to personality disorders [42]. Diagnostic concordance is particularly low in forensic assessment of mental insanity and diminished capacity as the adversarial legal system forces differing readings of the same clinical data. One common problem in this context is malingering, that is the fabrication or exaggeration of symptoms in order to obtain a favorable verdict; indeed faked psychiatric symptoms can be hard to detect with a clinical evaluation alone. The use of genetic and neuroimaging data cannot change the rationale underlying the determination of criminal liability;

this must be based on a causal association between a mental disorder and a crime. However, the use of such data may be crucial in providing objective, biological data which can be used to reduce uncertainty in forensic psychiatric evaluations and validate symptoms as non-faked, thereby minimizing the risk that psychiatric symptoms are the result of malingering [41••]. In no way are we claiming that the presence of risk genes or neuronal abnormalities could be the basis of any mental insanity assessment in the absence of clinical manifestations; rather, our point is that this biological information may be useful in forming psychiatric assessment. In the past, judges decided not to admit expert testimony including genetic and neuroscientific data (see [43] for a historical summary). However, the defendant's genetic, imaging and neuropsychological profile was taken into consideration by the Court in two recent cases, the first one in Italy, in a case examined by our group (http://www.personaedanno.it/cms/data/articoli/files/016153_resource1_orig.pdf) and the other one in the US (http://www.npr.org/templates/story/story.php?storyId=128043329).

One potential obstacle to the use of biological data to inform psychiatric diagnosis is that the above genetic and neuroscientific studies detected differences between groups using standard analytical methods based on classical statistics; however, for genetic and neuroimaging techniques to be useful in a forensic setting, one must be able to make inferences at individual rather than group level. This might be possible using machine learning techniques which allow the classification of individual observations into distinct groups based on high-dimensional data [44]. Support Vector Machine (SVM), for example, comprises a 'training' phase, in which well characterized training data are used to develop an algorithm which captures the key differences between groups, and a 'testing' phase in which the algorithm is used to predict the group to which a new observation belongs to. SVM can be used to make inferences at the level of the individual and as such has high translational potential in a forensic setting. So far, this method has been used for diagnostic and prognostic purposes in neurological and psychiatric patients with promising results (e.g. [45–48]). There is also evidence that discrimination can be improved by integrating genetic and neuroimaging data within a single classification model [49]; this suggests that genetic and neuroimaging data may index partially complementary aspects of the disorder under investigation. The application of machine learning techniques in a forensic setting could provide a biologically informed and objective means of improving psychiatric forensic assessment of a given individual. However, it must be acknowledged that the use of these techniques to establish the presence of psychiatric disorders is unlikely to result in a discrimination accuracy of 100%. This is because there are no biological markers for complex psychiatric disorders, which are likely to be associated with several etiopathological factors. A further complication is that psychopathy and deviant behavior may consist of several distinct subtypes; however, there is no agreement on this issue in the literature [31•]. Nevertheless, genetic and neuroimaging data may be able to inform forensic psychiatric assessment when used in combination with standard clinical measures.

## Lie and autobiographical memory detection

Another topical issue is the use of cognitive neuroscience for lie or autobiographical memory detection. In this regard positions have been and still are quite diverging. Some (e.g. [50]) have argued that the use of functional MRI (fMRI) for lie and memory detection in a forensic setting is premature; this is because brain activation as measured using functional neuroimaging techniques is intrinsically noisy and is influenced by several potential confounding variables [50]. However, others (e.g. [51]) have noted that neuroscience methods compare favorably, as regards accuracy and validity, to other trial-accepted methods such as psychodiagnostics and clinical psychiatric assessment. Furthermore, Schauer [51] notes that even a far from perfect method may be sufficient, in adversarial criminal systems, to instil in the jury the reasonable doubt that leads to not guilty verdicts. He recalls that evidence in a criminal trial is asymmetric with the prosecutor required to give convincing evidence to overcome reasonable doubts, whereas the defence may only prove that there is such a reasonable doubt. On this view the accuracy and reliability of prosecutor evidence are different from those of the defence. Brown and Murphy [50] have suggested, on argumentative grounds, that neuroimages are substantially more persuasive than traditional forms of testimony and therefore could exert undue influence on the jury. However, Schweitzer and colleagues [52] conducted an empirical study on a large group of jury-eligible subjects and found no evidence that neuroimages affected jurors' judgments over and above verbally described reports of the same content.

Different types of lies are thought to require different levels of cognitive load. For example, cognitive load may be minimal when simply denying a fact that actually happened but high when fabricating complex lies such as when Ulysses, the Odyssey hero, told Polyphemus his real name was 'Noman'. A number of fMRI studies have examined the brain correlates of lie production. The results have not always been consistent and this could be due to the fact that different studies examined different types of lies requiring different levels of cognitive load. A consistent finding is activation of the anterior cingulate cortex (ACC) and the dorsolateral prefrontal cortex (DLPFC) for lie-versus-truth telling; these regions are believed to be linked to two distinct cognitive phases in lie production [53]. Whereas the ACC is thought to be involved in suppression of the default truth response, the DLPFC is thought to be involved in the production of a credible substitution (the lie). Before these findings can have a practical application in a forensic setting, it is important to prove their reliability and validity not only at group level but also at single case level. To date machine learning techniques have been applied to lie detection showing promising high-accuracy diagnostics on single cases [54].

Whereas lie detection aims to identify whether an overt verbal response is a truthful response or a lie, memory detection tries to establish the presence or absence of specific autobiographical memory by comparing events which are known to the individual against events which may or may not be known. In recent years, memory detection has been investigated using a range of cognitive [55], psychophysiological [56] and neuroimaging [57,58••] techniques. The Concealed Information Test (CIT) is a standard paradigm in which a set of crime-related stimuli are presented with only one stimulus which is known to the guilty suspect. Ganis *et al.* [58••] recently showed that, using machine learning techniques with two regions of interest (the right lateral prefrontal and the anterior medial prefrontal cortex), it was possible to differentiate, at single individual level, between the 'no knowledge' and the 'concealed knowledge' conditions with 100% accuracy from fMRI data. A slightly lower accuracy in detecting individual memories (75–85%) was reported by Rissman *et al.* [59] for distinguishing between previously seen and unseen faces. The accuracy of lie detection and memory detection using psychophysiological (e.g. [60]) and cognitive (e.g. [61]) paradigms can be reduced using so-called 'countermeasures' and in a recent investigation, Ganis *et al.* [58••] showed that memory detection using fMRI has the same problem. The authors instructed individuals to make covert actions to the stimuli they do not know (such as moving imperceptibly one of their fingers) and found that this simple countermeasure was effective in reducing the diagnostic accuracy from 100 to 30%. This pattern of results show that fMRI-based measures can be susceptible to countermeasures, calling for caution before using these measures in real-world situations. Nevertheless, fMRI-based measures may provide information which, when considered in combination with other sources of evidence, might prove useful in a forensic setting. Furthermore, in the future, functional neuroimaging methods may improve their probative value by using techniques to counter disruptive countermeasures.

## Conclusion

In the present review, we have summarized the results of recent genetic and neuroscientific studies of deviant behavior and discussed their potential implications for the criminal system. We have argued that the use of genetic and neuroimaging methods cannot change the rationale underlying the determination of criminal liability, which must be based on a causal association between a mental disorder and a crime; however, these methods may provide objective, biological data which can be used to reduce controversy in forensic psychiatric evaluations of mental insanity and minimize errors in detecting malingering. In contrast, the probative value of fMRI-based measures for lie and memory detection is yet to be established due to their susceptibility to countermeasures.

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