

Brain abnormalities in antisocial individuals: implications for the law

Yaling Yang,¹ Andrea L. Glenn,¹ & Adrian Raine²

¹Department of Psychology, University of Southern California

²Department of Criminology, University of Pennsylvania

With the increasing popularity in the use of brain imaging on antisocial individuals, An increasing number of brain imaging studies have revealed structural and functional impairments in antisocial, psychopathic, and violent individuals. This review summarizes key findings from brain imaging studies on antisocial / aggressive behavior. Key regions commonly found to be impaired in antisocial populations include the prefrontal cortex (particularly orbitofrontal and dorsolateral prefrontal cortex), superior temporal gyrus, amygdala-hippocampal complex, and the anterior cingulate cortex. Key functions of these regions are reviewed to provide a better understanding on how deficits in these regions may predispose to antisocial behavior. Objections to the use of imaging findings in a legal context are outlined, and alternative perspectives raised. It is argued that brain dysfunction is a risk factor for antisocial behavior and that it is likely that imaging will play an increasing (albeit limited) role in legal decision-making.

According to a large-scale meta-analytic review of mental health in worldwide prison systems, 5,113 of 10,797 male prisoners (47%) were diagnosed with antisocial personality disorder (APD) (Fazel and Danesh, 2002). However, only about 3.7% of the male prisoners were diagnosed with a psychotic illness and 10% were diagnosed with major depression (Fazel and Danesh, 2002). Although the prevalence rate of APD in this study seems more conservative than a prior claim of a 50-80% APD rate in male prison populations (Widiger et al., 1996), the result nonetheless confirms the very close link between APD and criminal behavior. Granted, repeat violent criminal behavior is a defining feature of APD, but such a close connection between APD and crime has urged researchers to employ brain imaging techniques to study individuals with APD. The hope is that a better understanding of the neurobiological basis to antisocial aggressive behavior can facilitate the development of a new generation of biosocial treatment and prevention programs to tackle a disorder that is very costly to society.

The use of imaging techniques to test the structural and functional integrity of the antisocial brain has provided some groundbreaking findings, but has also raised some concerns regarding the use of the brain scan results in the legal system. In this review, we explore how brain imaging has increased our understanding of the neural bases underlying antisocial, psychopathic, and aggressive behavior and the potential implication of these findings for the law. Several issues will be addressed: First, do antisocial, psychopathic and aggressive individuals have a brain abnormality? Second, are impairments relatively widespread, or are they instead localized to one or perhaps two specific regions? Third, what is the functional significance of these regional abnormalities found in antisocial groups? And forth, should the scientific findings from brain imaging on antisocial criminals be used in legal cases?

BRAIN IMAGING FINDINGS ON ANTISOCIAL INDIVIDUALS

In the past few decades, several brain imaging techniques have been made available for studying psychiatric populations. Functionally, Positron Emission Tomography (PET), Single Photon Emission Computed Tomography (SPECT), and functional Magnetic Resonance Imaging (fMRI) are among the most commonly used techniques in revealing brain dysfunction in antisocial aggressive individuals. Structurally, anatomical Magnetic Resonance Imaging (aMRI) is a major tool employed by researchers in detecting volumetric abnormalities in any brain region in antisocial groups. Using

different mechanisms, each of the brain imaging technologies has its contribution in the search of the neural circuits underlying antisocial psychiatric behavior.

PET Findings in Antisocial Individuals

In the late 1980s, PET began to gain popularity among researchers studying brain functioning in antisocial, aggressive behavior. By injecting the subject with a short-lived radioactive tracer prior to the scan, glucose metabolism in regions-of-interest can be measured to detect any functional impairment. Many of the studies investigated the metabolic abnormality during resting states in antisocial individuals. In a case study of four psychiatric patients with a history of repetitive violence, Volkow and Tancredi (1987) found decreased metabolic activity in frontal and left temporal cortex. In a follow-up study, Volkow et al. (1995) observed significantly reduced glucose metabolism in both prefrontal and medial temporal regions in psychiatric patients with a history of violence compared with normal controls. Wong et al. (1997) also found significant reduced metabolism in the anterior inferior temporal cortex, bilaterally for non-repetitive and left-sided for repetitive violence offenders, compared with normal controls. Using aggressive children with epilepsy, Juhasz et al. (2001) found a significant correlation between higher severity of aggression and lower metabolism in the bilateral medial prefrontal and left temporal cortex.

In addition, some studies examined the metabolic abnormality in antisocial individuals by using a challenge task, most commonly a continuous performance task (CPT). Using an auditory activation task, Goyer et al. (1994) showed that the number of impulsive-aggressive acts in personality-disordered patients was negatively associated with glucose metabolism in the left anterior frontal and anterior medial frontal cortex. Raine et al. (1994) also found reduced glucose metabolism in the anterior medial prefrontal, orbitofrontal and superior frontal cortex in murderers compared to normal controls during a CPT task. In a follow-up study incorporating additional participants, Raine, Buchsbaum & LaCasse (1997) again found reduced glucose metabolism in the bilateral middle and medial frontal cortex as well as the left anterior medial prefrontal, right orbitofrontal cortex, left angular gyrus, and corpus callosum during a CPT task in 41 murderers compared to 41 matched controls. They also found abnormal asymmetries of functioning, with murderers showing lower left and increased right functioning in both the amygdala and hippocampus compared to controls (Raine et al., 1997). Using an auditory CPT task, significantly lower glucose metabolism in the right hypothalamus was found in male perpetrators of domestic violence compared to controls (George et al., 2004). Taken together, these studies indicate brain glucose metabolism abnormalities in antisocial individuals, particularly in the prefrontal and temporal regions.

SPECT Findings in Antisocial Individuals

Soon after the first PET studies were published, another brain imaging technique, SPECT, also began to be employed by researchers studying the brain function in antisocial populations. By injecting a gamma-emitting tracer (in most cases ^{99m}Tc -HMPAO or ^{99m}Tc -EC), the gamma rays emitted by the brain regions (which are proportional to their blood flow intakes) are detected by a gamma camera and the amount of regional cerebral blood flow (rCBF) is then determined. Kuruoglu et al. (1996) first published a study using SPECT in which alcoholics with APD showed significantly reduced frontal rCBF compared to both alcoholics with other personality disorders and nonalcoholic controls. Amen et al. (1996) also presented findings on aggressive individuals which showed decreased rCBF activity in the prefrontal cortex and increased activity in the anterior medial frontal and left temporal cortex. Reduced rCBF was also reported in the left anterior inferior temporal cortex in a group of violent offenders compared with non-repetitive violent offenders showing lower activity in the right anterior temporal cortex compared with repetitive violent offenders (Wong et al., 1997). Using 21 individuals convicted of impulsive violent offenses, aggressive dementia patients showed reduced rCBF in the left anterior temporal, bilateral dorsofrontal, and right parietal cortex compared to non-aggressive dementia patients (Hirono et al., 2000). Soderstrom et al. (2000) revealed reduced rCBF in the frontal cortex, temporal cortex (the hippocampus in particular), and the left angular gyrus in aggressive dementia patients compared to controls. The same research group found significant negative correlations between increased psychopathy scores and decreased rCBF in the orbitofrontal cortex, left temporal cortex, and left hippocampus in a group of violent offenders (Soderstrom et al., 2002). However, not all studies have found reduced blood flow in antisocial, aggressive individuals using SPECT. For example, Intrator et al. (1997) showed significantly increased rCBF in bilateral frontotemporal regions in drug-abusing psychopaths compared to drug-abusing non-psychopaths and controls during the processing of negative affect words. In summary, SPECT studies have found that antisocial aggressive individuals exhibiting reduced blood flow in the prefrontal cortex, temporal cortex and hippocampus. This technology has the same limitation as PET however in that it requires an injection of a tracer for acquiring images, making it somewhat less suitable for use in community samples.

fMRI Findings in Antisocial Individuals

The most recent development in functional imaging technology is the thriving usage of functional Magnetic Resonance Imaging (fMRI). Although still an indirect measure of neural activity, changes in the blood-oxygen-level dependent (BOLD) signal in response to a cognitive or emotional task can be captured in real time, allowing researchers to identify which brain regions are more utilized when performing a task. Because this technique is non-invasive and does not require an injection, its popularity among researchers has increased dramatically. Different emotional and cognitive tasks (e.g. fear-conditioning, working memory) have been utilized to study brain dysfunction in antisocial individuals with the common findings being abnormal activation in the amygdala, hippocampus and frontal regions. During the viewing of negative affective pictures, decreased activation was found in the amygdala-hippocampal complex in criminal psychopaths (Kiehl et al., 2001), the right dorsal anterior cingulate cortex in children with conduct disorders (Sterzer et al., 2005), and the right temporal and parahippocampal in psychopaths (Muller et al., 2003). However, increased activation was also reported in the frontotemporal (Kiehl et al., 2001) and the right prefrontal regions (Muller et al., 2003). In contrast, during the viewing of positive affect pictures, psychopaths were found to show decreased right medial prefrontal and increased left orbitofrontal activation (Muller et al., 2003).

Fearlessness is hypothesized to be a key characteristic of antisocial individuals and has been investigated using an aversive conditioning task. Schneider et al. (2000) found an increase in activation in the dorsolateral prefrontal cortex and amygdala during the acquisition phase of aversive conditioning in individuals with APD. Alternatively, Birbaumer et al. (2005) revealed that psychopaths showed no significant differential activation in the limbic-prefrontal circuit (amygdala, orbitofrontal cortex, insula, and anterior cingulate cortex), which was activated in healthy controls during a fear-conditioning task. Using a visual / verbal working memory task, Raine et al. (2001) showed significant reduced activation in the right hemisphere, particularly in the temporal cortex, in violent offenders with a history of abuse compared with controls. Again, using a working memory task, activation deficits in the left frontal gyrus and anterior cingulate cortex were found in APD patients compared with normal controls (Kumari et al., 2006). Another study by Kiehl et al. (2004) showed that criminal psychopaths failed to show the appropriate right anterior temporal activation when differentiating abstract from concrete words compared with healthy controls. This fMRI technology, although relatively new, has been providing some breakthroughs in revealing dysfunctions in the frontal, temporal and limbic regions in individuals with APD and psychopathy. Given its superior spatial resolution, fMRI is a promising tool in assist in identifying which subregions of which specific brain areas are impaired, together with the broader neural circuitry that may be disrupted in antisocial individuals.

aMRI Findings in Antisocial Individuals

In terms of structural abnormalities, aMRI has becoming the most common structural imaging used in examining brain structure in the past two decades. Several studies to date have found volumetric abnormalities in the prefrontal and temporal regions in antisocial individuals. One aMRI study involving a sample of 21 individuals with APD showed a significant gray matter volume reduction in the prefrontal cortex compared with normal controls, a substance-dependent control group, and also a broader psychiatric control group (Raine et al., 2000). Woermann et al. (2000) also found reduced left prefrontal gray volumes in aggressive epileptic patients compared to non-aggressive epileptic patients. Similarly, Laakso et al. (2002) reported reduced gray matter volume in dorsolateral prefrontal, medial frontal, and orbitofrontal cortex in alcoholics with antisocial personalities compared to controls. Dolan et al. (2002) found a volume reduction in the temporal lobe in patients with impulsive aggressive personality disorders, but no such reduction was found in the prefrontal cortex. More recently, Yang et al. (2005) found a volume reduction in prefrontal gray matter in unsuccessful psychopaths (caught) compared to both successful psychopaths (not caught) and also non-psychopathic controls. Overall, volumetric reduction have been found in the frontal, particularly dorsolateral and orbitofrontal prefrontal sub-region, and temporal cortex in antisocial aggressive individuals,

The relationship between APD and volumes of subcortical regions such as the hippocampus, and corpus callosum seem to be more complicated. Laakso et al. (2000) demonstrated reduced volume in right hippocampus in violent offenders with APD who were also early-onset alcoholics compared to controls. They also found volumetric reductions in the posterior hippocampus to be associated with increased psychopathy scores in antisocial alcoholics (Laakso et al., 2001). More complex structural abnormalities were reported by Raine et al. (2004) implicating abnormal asymmetry in the anterior hippocampus. More specifically, they found an exaggerated structural hippocampal asymmetry (right > left) in unsuccessful psychopaths compared with successful psychopaths and controls. Raine et al. (2003) assessed 15 antisocial psychopathic individuals and found increased callosal white matter volume, increased in callosal length, and reduced callosal thickness compared to 25 matched controls. Correlational analyses in the larger unselected sample of 83 subjects also confirmed the association between higher scores in psychopathic personality and larger callosal volumes (Raine et al., 2003). As suggested by the above studies, it is plausible that antisocial individuals have structural deficits in

the subcortical regions, particularly the hippocampus and corpus callosum. However, future study is clearly needed to allow drawing conclusion possible.

Summary of Brain Abnormalities in Antisocial Individuals

Based on the findings of the reviewed imaging studies described above, several brain regions have been repeatedly found to be impaired in antisocial, psychopathic, and aggressive individuals despite the type of imaging techniques used: the prefrontal cortex, superior temporal cortex, amygdala-hippocampal complex, and anterior cingulate cortex. In the frontal region, deficits in the prefrontal and anterior cingulate cortex contribute to impulsivity, irresponsibility, poor decision-making, and deficient emotional information processing in antisocial individuals. In the temporal regions, the amygdala-hippocampal and superior temporal impairments are likely to predispose to antisocial features such as the inability to follow the social rules, deficiency in moral judgment, and the failure to avoid punishment.

Although these brain imaging findings have been highly suggestive of a strong link between brain abnormalities and antisocial aggressive behavior, more questions are raised due to the fact that the antisocial groups studied contain some degree of within- and between-group heterogeneity. It is to our speculation that antisocial individuals with different characteristics, for example aggressive, institutionalized, or comorbid with other psychiatric disorders, may differ in the severity of brain abnormalities and also show impairments in different brain regions. By testing this hypothesis, in turn, could potentially explain the inconsistency among these studies. However, no systematic review to date has addressed such concerns.

REGIONAL BRAIN FUNCTIONS LINKED TO ANTISOCIAL BEHAVIOR

In recent years using healthy participants, functional imaging studies have been able to identify the key function performed by each component of the brain. It is our belief that it is extremely important to understand how the brain functions normally to better connect the cognitive/ emotional dysfunction and brain regional deficits found in antisocial individuals. By examining the anatomical connectivity and the key function of the regions found impaired in antisocial individuals (the prefrontal cortex, superior temporal gyrus, amygdala-hippocampal complex and anterior cingulate cortex), it may provide some insights into how deficits in these regions predispose to antisocial, aggressive personalities.

Prefrontal Functioning

For many years, the approach to evaluating the structural and functional integrity of the prefrontal cortex was simply to examine the prefrontal cortex as a whole. However, with the increasing knowledge base on brain imaging in healthy individuals in the past 20 years, it is now recognized that this region, which was once considered a unitary structure, is a composite of anatomically and functionally distinct subsystems. In particular, major differentiations have been made between the functional properties of the orbitofrontal and dorsolateral sectors (Damasio, 1994; Lapiere et al., 1995).

The orbitofrontal regions including the orbitofrontal cortex (OFC) and the ventromedial prefrontal cortex (VMPFC) are densely connected with many brain regions including the basal ganglia, amygdala, and other prefrontal surrounding areas. Both the location and the anatomical connectivity allow these regions to receive and process the information concerning emotion and reward values, and output such information to the dorsolateral prefrontal cortex for final execution. Recent fMRI studies have shown that the orbitofrontal regions, the VMPFC in particular, are activated during ethical decision-making and moral reasoning. For example, Greene et al. (2001) revealed that the VMPFC, as well as the anterior dorsolateral prefrontal cortex, is activated in response to reasoning about different ethical dilemmas. Moll et al. (2002) again reported increased activation in the OFC during the viewing of scenes that evoke moral emotions (i.e. physical assaults, war scenes, abandoned children). Similarly, Heekeren et al. (2003) showed activation in the bilateral VMPFC during simple moral decisions compared to semantic decisions. The strong and replicable involvement of the VMPFC and the OFC in moral decision-making processes is indicated in the above studies as well as supported by several reviews on brain circuits underlie moral reasoning (Casebeer, 2003; Greene and Haidt, 2002; Moll et al., 2003). In combination with findings showing orbitofrontal deficits in antisocial individuals (i.e. Laakso et al., 2002; Raine et al., 1997), it is possible that the dysfunction in the OFC plays important roles in the neural circuits that underlie poor inhibitory control, moral decision-making, and reward/ punishment processing in these individuals (Blair, 2003; Kiehl, 2005; Raine & Yang, 2006).

The other key prefrontal subregion, the dorsolateral prefrontal cortex (DLPFC), receives inputs from surrounding regions, while also monitoring and manipulating information in the ventrolateral prefrontal cortex (VLPFC) (Petrides,

1994, 1996; Owen et al., 1996). By monitoring the VLPFC, a region that encodes and retrieves information from the OFC, amygdala, and temporal cortex, the DLPFC is considered to be a key brain area involved in the execution of several cognitive functions (or so-called “executive functions”) such as the ability to plan, organize, regulate, shift strategy, and override a strong response tendency (i.e. attention-set shifting). Several fMRI studies have tested the involvement of the DLPFC in the executive functions described above by using inhibition control tasks, showing increased activation in this region during response inhibition (Garavan et al., 1999; Liddle et al., 2001; Horn et al., 2003). Therefore, it is our prediction that the DLPFC deficits found in antisocial individuals (i.e. Laakso et al., 2002; Hirono et al., 2000) may be involved in antisocial features such as response perseveration, which results in a life-long antisocial behavior despite repeated punishment, poor planning, and organizing ability, which leads to an occupationally and socially dysfunctional lifestyle (Raine and Yang, 2006).

Superior Temporal Functioning

The superior temporal gyrus (STG), particularly the auditory cortex and Wernicke’s area, is directly connected with the orbitofrontal, medial and lateral prefrontal cortex as well as the limbic system. Several fMRI studies have suggested that the STG (particularly the posterior section), in addition to the orbitofrontal regions described earlier, shows increased activation in response to moral decision-making tasks (Greene et al., 2001; Moll et al., 2002; Heekeren et al., 2003). Another crucial ability mediated by the STG is “theory of mind”. Human beings, as social animals, have the social cognitive ability to anticipate other people’s behavior based on prior experiences or instincts, an exceptional capacity known as “theory of mind”. This mentalizing ability allows us to attribute mental states, whether it’s desire or intention, to ourselves and to others (commonly known as the ability to place oneself in another’s shoes), and thus plays a central role in efficient social interaction. Several functional studies have provided evidence supporting the link between the STG and “theory of mind” (Fletcher et al., 1995; Baron-Cohen et al., 1999; Brunet et al., 2000; Castelli et al., 2000; Vogeley et al., 2001; McCabe et al., 2001). As shown in these studies, the STG is centrally involved in moral decision-making and “theory of mind”, suggesting that the integrity of this region is important for efficient social function and communication. Therefore, deficits in the STG as shown in several studies (i.e. Intrator et al., 1997; Soderstrom et al., 2002) may result in dysfunction in the abilities discussed above and predispose to antisocial features such as lack of concern regarding the impact of their actions to others and non-compliance with societal rules (Raine and Yang, 2006).

Amygdala-Hippocampal Functioning

The amygdala is located in the medial temporal cortex and receives information from the prefrontal cortex, thalamus, and associated areas, while the hippocampus is situated medially to the lateral ventricles and is densely interconnected with the amygdala, forming the amygdala-hippocampal complex. fMRI studies in recent years suggest the amygdala-hippocampal complex is likely to be one of the most important brain regions underpinning the processing of affective stimuli, particularly stimuli which contain negative emotion such as fear and threat. For example, Whalen et al. (1998) showed significantly increased amygdala activation in response to masked fearful faces and decreased activation when seeing masked happy faces. Another study conducted by Hariri et al. (2002) showed increased activation in the bilateral amygdala during the perception of threatening pictures meant to induce a fearful response. Regarding the hippocampus, the importance of this region in the recollection of events including acquired emotional memory has been demonstrated in several patient studies (i.e. Duzel et al., 2001; Yonelinas et al., 2002). In summary, it can be concluded from the above studies that the amygdala is responsible for processing threat- or fear-related stimuli while the hippocampus is involved in remembering facts and contextual information regarding negative stimuli. Taken together, the amygdala-hippocampal dysfunction found in several antisocial groups (i.e. Raine et al., 1997; Kiehl et al., 2001) may be linked to poor fear conditioning and impaired emotional regulation in antisocial psychopathic individuals (Blair, 2003; Kiehl, 2005; Raine and Yang, 2006).

Anterior Cingulate Functioning

The anterior cingulate cortex (ACC), a part of the limbic system, has rich bidirectional connections with the prefrontal cortex, parietal lobe, hypothalamus, amygdala and hippocampus. The rostral section of the ACC, also known as the “affective” subdivision, is involved in emotional information processing and the regulation of emotional responses (Bush et al, 2000). It is crucial in interpreting emotional cues and suppressing anger/ agitation in order to maintain efficient interpersonal communication. The caudal section, by contrast, is known as the “cognitive” subdivision, and is involved in detecting conflicts, and monitoring errors, which is key to everyday problem-solving (i.e. Allman et al, 2001; Frith and Dolan, 1997; Kerns, 2006). In addition, lesion studies also show that patients with damage to the ACC show symptoms including lack of empathy, shallow affect, poor error monitoring, and abnormal response inhibition (Mesulam, 2000; Swick and Jovanovic, 2002; Swick and Turken, 2002). The lesion studies, along with studies showing impairment

in the ACC in antisocial aggressive individuals (i.e. Kiehl et al, 2001, New et al, 2002), support the hypothesis that the ACC dysfunction may predispose antisocial psychopathic behavior such as perseveration and poor emotion regulation (Kiehl, 2005; Raine and Yang, 2006).

THE USE OF BRAIN IMAGING IN LEGAL DEFENSES

Brain imaging research suggesting that antisocial behavior may be associated with differential brain structure and function is likely in the long-term to have significant implications for some sectors of the legal system. In criminal cases, brain imaging could be used in insanity defenses (e.g. *People v. Weinstein*, 1992), as an indicator of criminal intent, in detecting deception by witnesses or defendants, and in determining appropriateness of the death penalty. It may also be used in the formation or alteration of laws, for example, whether to limit access to violent video games because they may increase aggressive behavior. Despite uncertainties regarding the accuracy and interpretation of brain imaging, especially in case-specific instances, the legal system has been quick to incorporate brain imaging evidence into the courts. PET and/or SPECT brain imaging evidence has been used in approximately 130 reported court cases, and fMRI evidence has been employed in two (Feigenson, 2006). Furthermore, evidence has also been cited in briefs that may influence court decisions.

One of the first cases to admit brain imaging evidence was the high profile trial of John Hinckley Jr. who was accused of the attempted assassination of President Ronald Regan in 1981. The defense presented a computed tomography (CT) scan of Hinckley's brain, arguing that the observed "widening" of sulci (likely reflecting cortical atrophy) looked similar to the brains of schizophrenia patients. Hinckley was found not guilty by reason of insanity (*U.S. v. Hinckley*, 1989). Since then, brain imaging has been used in similar ways in attempts to demonstrate that a defendant's actions may have resulted in part from abnormal brain functioning, thus questioning issues of responsibility and appropriateness of punishment. One of the authors (AR) testified to this effect in a rape and murder case. PET scans of the defendant revealed reduced brain activity in the ventrolateral, ventromedial, and polar regions of the prefrontal cortex. He argued that such brain dysfunction, which may have resulted from severe physical abuse and head injuries in childhood, could predispose to poor decision-making, lack of self-insight, lack of affect, and poor behavioral control which in turn predisposes to callous, disinhibited behavior. The defendant was found guilty, but spared the death penalty based in part on the reasoning that impaired capacity due to brain damage likely limited the defendant's ability to appreciate the wrongfulness of his acts. As brain imaging technology advances, and as more studies of the neurobiology of criminal behavior are conducted, the use of brain imaging evidence in court is likely to become even more prevalent.

Brain imaging research also has implications in legislative decisions related to antisocial behavior. In the first case to employ fMRI, evidence was provided in an attempt to demonstrate that minors who play violent video games show less activity in the frontal cortex, and therefore anti-violent video game legislation should be enforced (*Entertainment Software Assoviation et al. v. Blagojevich*, 2005). The state argued that the reduction in frontal lobe activity was similar to brain activity patterns observed in clinically diagnosed violent or aggressive adolescents. However, criticisms regarding experimental design and whether brain activity is an accurate measure of mental function resulted in the decision that laws banning violent video games violate the First Amendment.

More recently, brain imaging evidence was influential in the U.S. Supreme Court case regarding capital punishment of juveniles (*Roper v. Simmons*, 2005). The American Medical Association and the American Psychiatric Association, among others, issued a brief suggesting that adolescents may not have the ability to exercise adult impulse control, may underestimate risks, and are less capable of controlling their emotions because their brains have not fully matured. They cited evidence from numerous brain imaging studies (Giedd, 1999; Sowell et al. 2001) finding that complete myelination of neurons in the prefrontal cortex does not occur until ages 18-25 and therefore it is unconstitutional to implement such severe punishment for juveniles. In 2005, the Supreme Court ruled that it is unconstitutional to impose the death penalty for adolescents under the age of 18.

Brain imaging evidence suggesting that brain regions associated with regulating impulses and aggression may not be fully developed in adolescents or may not function properly in some adults raises serious questions regarding the moral culpability of adult criminals. Whether brain imaging evidence should be admitted in courts is likely to become an important issue in criminal justice. Several researchers have raised concerns with the use of brain imaging in the legal system (Eastman & Campbell, 2006; Garland & Glimcher, 2006; Kulynych, 1997; Mandavilli, 2006; Mobbs et al., 2007) arguing that problems can arise when scientific literature designed for experimental purposes is implemented in a legal context. Many believe that the limitations of brain imaging research may not be fully realized at this point in time,

potentially leading to dangerous legal or social judgments about people's behavior. Mobbs et al. (2007) outlines several limitations in the use of brain imaging in the legal system: brain imaging cannot tell what a person was thinking at the time of an action, brain imaging is only one source of information regarding influences on behavior, the interpretation of brain scans is subjective and individually variable, and brain imaging evidence lacks diagnostic and predictive validity. In addition, Mobbs et al. and others (e.g. Farah, 2004) warn that the use of brain images in the courtroom may be too influential for jurors who may view the brightly colored images as more accurate and objective than they actually are.

On a more theoretical level, Eastman & Campbell (2006) claim that there is a fundamental mismatch between the questions the legal system asks and the questions science can answer; at present, neuroscience cannot answer questions regarding particular individuals, but can only make statements about increased likelihoods due to membership in a group of individuals with similar characteristics. Neurobiological evidence from empirical studies has not been designed for practical application in the courtroom; thus it can be argued that the use of such evidence poses a risk to the proper exercise of justice.

An alternative perspective to the concerns raised about using brain imaging in courts should also be considered. Many of the arguments and limitations given appear to be based on the idea that brain imaging is used as a form of brain-print in isolation from all other evidence to unequivocally type an individual and demonstrate causality. In reality, brain imaging evidence should be considered in the same way as evidence from any other biological, psychological, or psychosocial source; brain structure and function is meant to be viewed as one factor among many that may predispose to, increase probability of, or influence behavior. Scientific information from group studies (e.g. childhood abuse predisposing to adult violence) is often used in court cases to argue for increased risk for violence in a specific individual, and does not imply the existence of a one-to-one causal relationship; brain imaging evidence from group studies should be treated no differently. Furthermore, brain imaging evidence is subjective in the same way that eye-witness testimony, psychological assessments, or the interpretation of other types of medical evidence are subjective, which is why it is important to involve expert witnesses who can objectively explain and interpret the evidence in a clear, unbiased manner. Once normative data sets are built up, imaging data can ultimately be interpreted objectively in the same way that IQ is. Finally, brain imaging can produce persuasive visuals in the same way that disturbing photographs, graphic testimonies of torture or child abuse, or persuasive expert witnesses can be influential to jurors, emphasizing the need for imaging data to be as thoroughly explained and scrutinized as any other evidence. Thus, when brain imaging evidence is applied to questions within accepted boundaries and is treated under same standards as other forms of evidence, it has the potential to make a useful contribution in legal decision-making.

Morse (2004) argues that neuroscience may have a long way to go before it will begin to have widespread influence in the legal arena. Currently the law treats people as intentional, practical reasoners, not as purely mechanistic beings of the causal universe. While neuroscience may uncover some of the causal mechanisms that influence our behavior, Morse believes it is unlikely that neuroscience will be able to revolutionize our conceptions of ourselves to the extent that we no longer treat ourselves as rational, intentional agents with ultimate control over our actions. Similarly, Eastman & Campbell (2006) argue that only if we are able to achieve a very high level of biological understanding of ourselves, such that we have essentially explained away personhood, would legal determination of responsibility be reliant on neuroscience. An alternative perspective is that taking into account documented risk factors for violence in some specific cases does not mean that we have to completely abandon our general concepts of rationality, personhood, and responsibility.

While brain imaging may be far from completely revolutionizing the legal system, it is clear that as neuroscience delves deeper into the exploration of criminal behavior, the potential for its use in courts will only increase. Ultimately, a high level of communication between scientists and legal officials is essential in order to appropriately integrate the new and potentially important findings from brain imaging research into the way society views, and deals with, criminal behavior.

REFERENCES

- Allman, J. M., Hakeem, A., Erwin, J. M., Nimchinsky, E., Hof, P. (2001) The anterior cingulate cortex. The evolution of an interface between emotion and cognition. *Annals of the New York Academy of Sciences*, 935, 107-117.
- Amen, D. G., Stubblefield, M., Carmichael, B., & Thisted, R. (1996). Brain SPECT findings and aggressiveness. *Annals of Clinical Psychiatry*, 8, 129-137.
- Baron-Cohen, S., Ring, H. A., Weelwright, S., Bullmore, E. T., Brammer, M. J., Simmons, A., & Williams, S. C. (1999) Social intelligence in the normal and autistic brain: an fMRI study. *European Journal of Neuroscience*, 11, 1891-1898.
- Birbaumer N., Veit R., Lotze M., Erb M., Hermann C., Grodd W., & Flor H. (2005) Deficient fear conditioning in psychopathy. *Archives of General Psychiatry*, 62, 799-801.
- Blair, R. J. R. (2003). Neurobiological basis of psychopathy. *British Journal of Psychiatry*, 182, 5-7.
- Brunet, E., Sarfati, Y., Hardy-Bayle, M. C., & Decety, J. (2000) A PET investigation of the attribution of intentions with a nonverbal task. *Neuroimage*, 11, 157-166.
- Bush, G., Luu, P., & Posner, M. I. (2000) Cognitive and emotional influences in anterior cingulate cortex. *Trends in Cognitive Sciences*, 4, 215-222.
- Casebeer, W. D. (2003) Moral cognition and its neural constituents. *Nature Reviews. Neuroscience*, 4, 840-846.
- Castelli, F., Happe, F., Frith U., & Frith C. (2000) Movement and mind: a functional imaging study of perception and interpretation of complex intentional movement patterns. *Neuroimage*, 12, 314-325.
- Damasio A. R. (1994) Descartes' error and the future of human life. *Scientific American*. 271: 144.
- Dolan, M. C., Deakin, J. F. W., Roberts, N., & Anderson, I. M. (2002). Quantitative frontal and temporal structural MRI studies in personality-disordered offenders and control subjects. *Psychiatry Research Neuroimaging*, 116, 133-149.
- Duzel, E., Vargha-Khadem, F., Heinze, H. J., & Mishkin, M. (2001) Brain activity evidence for recognition without recollection after early hippocampal damage. *Proceedings of the National Academy of Science*, 98, 8101-6.
- Eastman, N. & Campbell, C. (2006). Neuroscience and legal determination of criminal responsibility. *Nature Neuroscience*, 7, 311-318.
- Entertainment Software Association et al. v. Blagojevich, 404 1051 (Supp. 2d 2005).
- Farah, M. J. (2004). Neuroethics: A guide for the perplexed. *Cerebrum*, 6, 29-38.
- Fazel, S., & Danesh, J. (2002) Serious mental disorder in 23000 prisoners: a systematic review of 62 surveys. *Lancet*, 359, 545-550.
- Feigenson, N. (2006). Brain imaging and courtroom evidence; on the admissibility and persuasiveness of fMRI. *International Journal of Law in Context*, 2, 233-255.
- Fletcher, P. C., Happe, F., Frith, U., Baker, S. C., Dolan, R. J., Frackowiak, R. S., Frith, C. D. (1995) Other minds in the brain: a functional imaging study of "theory of mind" in story comprehension. *Cognition*, 57, 109-128.
- Frith, C., & Dolan, R. J. (1997) Brain mechanisms associated with top-down processes in perception. *Philosophical transactions of the Royal Society of London*, 352, 1221-30.
- Garavan, H., Ross, T. J., & Stein, E. A. (1999). Right hemispheric dominance of inhibition control: An event-related functional MRI study. *Proceedings of the National Academy of Science*, 96: 8301-8306.
- Garland, B. & Glimcher, P. W. (2006). Cognitive neuroscience and the law. *Current Opinion in Neurobiology*, 16, 130-134.

- Geidd, J.N. (1999). Brain development during childhood and adolescence: A longitudinal MRI study. *Nature Neuroscience*, 2, 861.
- George, D. T., Rawlings, R. R., Williams, W. A., Phillips, M. J., Fong, G., Kerich, M., Momenan, R., Umhau, J. C., & Hommer, D. (2004) A select group of perpetrators of domestic violence: evidence of decreased metabolism in the right hypothalamus and reduced relationships between cortical/ subcortical brain structures in position emission tomography. *Psychiatry Research*, 130, 11-25.
- Goyer, P. F., Andreason, P. J., Semple, W. E., and Clayton, A. H. (1994). Positron-emission tomography and personality disorders. *Neuropsychopharmacology*, 10, 21-28.
- Greene, J., & Haidt, J. (2002) How (and where) does moral judgment work? *Trends Cognitive Sciences*, 6, 517-523.
- Greene J. D., Sommerville R. B., Nystrom L. E., Darley J. M. & Cohen J. D. (2001) An fMRI investigation of emotional engagement in moral judgment. *Science*, 293: 2105-8.
- Hariri, A. R., Mattay, V. S., Tessitore, A., Fera, F., & Weinberger D. R. (2002) Neocortical modulation of the amygdala response to fearful stimuli. *Biological Psychiatry*, 53: 494-501.
- Heekeren H. R., Wartenburger I., Schmidt H., Schwintowski H., & Villringer A (2003) An fMRI study of simple ethical decision-making. *Neuroreport*, 14: 1215-1219.
- Hirono N., Mega M. S. Dinov I. D., Mishkin F. & Cummings J. L. (2000) Left frontotemporal hypoperfusion is associated with aggression in patient with dementia. *Archives Neurology*, 57: 861-6.
- Horn N. R., Dolan M., Elliott R., Deakin J. F. W., & Woodruff P. W. R. (2003) Response inhibition and impulsivity: an fMRI study. *Neuropsychologia*, 41: 1959-1966.
- Intrator J., Hare R., Stritzke P., Brichswein K., Dorfman D., Harpur T., Bernstein D., Handelsman L., Schaefer C., Keilp J., Rosen J., & Machac J. (1997) A brain imaging (Single Photon Emission Computerized Tomography) study of semantic and affective processing in psychopaths. *Biological Psychiatry*, 42: 96-103.
- Juhasz, C., Behen, M. E., Muzik, O., Chugani, D. C., & Chugani, H. T. (2001). Bilateral medial prefrontal and temporal neocortical hypometabolism in children with epilepsy and aggression. *Epilepsia*, 42, 991-1001
- Kerns, J. G. (2006) Anterior cingulate and prefrontal cortex activity in an fMRI study of trial-to-trial adjustments on the Simon task. *Neuroimage*, 33, 399-405.
- Kiehl K.A., Smith A.M., Hare R.D., Mendrek A., Forster B.B., Brink J., Brink J., & Liddle P.F. (2001) Limbic abnormalities in affective processing by criminal psychopaths as revealed by functional magnetic resonance imaging. *Biological Psychiatry*, 50: 677-84.
- Kiehl K.A., Smith A.M., Mendrek A., Forster B.B., Hare R.D., & Liddle P.F. (2004) Temporal lobe abnormalities in semantic processing by criminal psychopaths as revealed by functional magnetic resonance imaging. *Psychiatry Research Neuroimaging*, 130: 27-42.
- Kiehl K. A. (2006) A cognitive neuroscience perspective on psychopathy: Evidence for paralimbic system dysfunction. *Psychiatry Research*, 142, 107-128.
- Kulynych, J. (1997). Psychiatric neuroimaging evidence: a high-tech crystal ball? *Stanford Law Review*, 49, 1249-1270.
- Kumari, V., Das, M., Hodgins, S., Zachariah, E., Barkataki, I, Howlett, M., & Sharma, T. (2005) Association between violent behavior and impaired prepulse inhibition of the startle response in antisocial personality disorder and schizophrenia. *Behavioral Brain Research*, 158, 159-66.
- Kuruoglu, A. C., Arikan, Z., Vural, G., and Karatas, M. (1996). Single photon emission computerised tomography in chronic alcoholism: Antisocial personality disorder may be associated with decreased frontal perfusion. *British Journal of Psychiatry*, 169, 348-354.

- Laakso M. P., Vaurio O., Savolainen L., Repo E., Soininen H., & Tiihonen J. (2000) A volumetric MRI study of the hippocampus in type 1 and 2 alcoholism. *Behavioral Brain Research*, 109: 177-86.
- Laakso M. P., Vaurio O., Koivisto E., Savolainen L., Eronen M., Aronen H. J., Hakola P., Repo E., Soininen H., & Tiihonen J. (2001) Psychopathy and the posterior hippocampus. *Behavioral Brain Research*, 118: 187-93.
- Laakso, M. P., Gunning-Dixon, F., Vaurio, O., Repo, E., Soininen, H., & Tiihonen, J. (2002). Prefrontal volume in habitually violent subjects with antisocial personality disorder and type 2 alcoholism. *Psychiatry Research Neuroimaging*, 114: 95-102.
- Lapierre D, Braun CM, & Hodgins S. (1995) Ventral frontal deficits in psychopathy: Neuropsychological test findings. *Neuropsychologia*, 33: 139-151.
- Liddle P. F., Kiehl K. A. & Smith A. M. (2001) Event-related fMRI study of response inhibition. *Human Brain Mapping*, 12: 100-109.
- Mandavilli, A. (2006). Actions speak louder than images. *Nature*, 444, 664-665.
- McCabe, K., Houser, D., Ryan, L., Smith, V., & Trouard, T. (2001) A functional imaging study of cooperation in two-person reciprocal exchange. *Proceedings of the National Academy of Science*, 98, 11832-5.
- Mesulam, M. (2000) Brain, mind, and the evolution of connectivity. *Brain Cognition*, 42, 4-6.
- Mobbs, D., Lau, H. C., Jones, O. D. & Frith, C. D. (2007). Law, responsibility, and the brain. *Public Library of Science: Biology*, 5, e103.
- Moll J., de Oliveira-Souza R., Eslinger P. J., Bramati I. E., Mourao-Miranda J., Andreiuolo P. A., & Pessoa L. (2002) The neural correlates of moral sensitivity: A functional magnetic resonance imaging investigation of basic and moral emotions. *The Journal of Neuroscience*, 22: 2730-2736.
- Moll, J., de Oliveira-Souza, R., & Eslinger, P. J. (2003) Morals and the human brain: a working model. *Neuroreport*, 14, 299-305.
- Morse, S. J. (2004). New neuroscience, old problems: Legal implications of brain science. *Cerebrum*, 6, 81-90.
- Muller J. L., Sommer M., Wagner V., Lange K., Taschler H., Roder C. H., Schuierer G., Klein H. E., & Hajak G. (2003) Abnormalities in emotion processing within cortical and subcortical regions in criminal psychopaths: Evidence from a functional magnetic resonance imaging study using pictures with emotional content. *Psychiatry Research Neuroimaging*, 54: 152-162.
- Owen, A. M., Evans, A. C., & Petrides, M. (1996) Evidence for a two-stage model of spatial working memory processing within the lateral frontal cortex: a positron emission tomography study. *Cerebral Cortex*, 6, 31-8.
- People v. Weinstein, 591 715 (Sup. Ct. 1992).
- Petrides, M. (1994) Frontal lobes and behaviour. *Current Opinion in Neurobiology*, 4, 207-11.
- Petrides, M. (1996) Specialized systems for the processing of mnemonic information within the primate frontal cortex. *Philosophical transactions of the Royal Society of London*, 351, 1455-61.
- Raine A., Buchsbaum M., & LaCasse L. (1997) Brain abnormalities in murderers indicated by positron emission tomography. *Biological Psychiatry*, 42: 495-508.
- Raine, A., Buchsbaum, M., Stanley, J., Lottenberg, S., Abel, L. & Stoddard, J. (1994). Selective reductions in prefrontal glucose metabolism in murderers. *Biological Psychiatry*, 36, 365-73.
- Raine, A., Ishikawa, S. S., Arce, E., Lencz, T., Knuth, K. H., Bihrl, S., LaCasse, L., & Colletti, P. (2004). Hippocampal structural asymmetry in unsuccessful psychopaths. *Biological Psychiatry*, 55: 185-91.
- Raine, A., Lencz, T., Bihrl, S., LaCasse, L., & Colletti, P. (2000). Reduced prefrontal gray matter volume and reduced autonomic activity in antisocial personality disorder. *Archives of General Psychiatry*, 57: 119-127.

- Raine A., Lencz, T., Taylor K., Hellige J. B., Bihrlle, S., LaCasse, L., Lee M., Ishikawa S. & Colletti, P. (2003) Corpus callosum abnormalities in psychopathic antisocial individuals. *Archives of General Psychiatry*, 160: 1627-35.
- Raine, A., Park, S., Lencz, T., Bihrlle, S., LaCasse, L., Widom, C. S. et al. (2001). Reduced right hemisphere activation in severely abused violent offenders during a working memory task: An fMRI study. *Aggressive Behavior*, 27, 111-129.
- Raine, A. & Yang, Y. (2006) Neural foundations to moral reasoning and antisocial behavior. *Social Cognitive and Affective Neuroscience*, Doi: 10.1093/scan/nsi033
- Roper v. Simmons, 125 1183 (Sup. Ct. 2005).
- Schneider F., Habel U., Kessler C., Posse S., Grodd W., & Muller-Gartner H. (2000) functional imaging of conditioned aversive emotional responses in antisocial personality disorder. *Neuropsychobiology*, 42: 192-201.
- Soderstrom, H., Tullberg, M., Wikkelsoe, C., Ekholm, S., & Forsman, A. (2000). Reduced regional cerebral blood flow in non-psychotic violent offenders. *Psychiatry Research: Neuroimaging*, 98, 29-41.
- Sterzer P., Stadler C., Krebs A., Kleinschmidt A., & Poustka F. (2005) Abnormal neural responses to emotional visual stimuli in adolescents with conduct disorder. *Biological Psychiatry*, 57: 7-15.
- Swick, D., & Jovanovic, J. (2002) Anterior cingulate cortex and the Stroop task: neuropsychological evidence for topographic specificity. *Neuropsychologia*, 40, 1240-53.
- Swick, D., & Turken, A. U. (2002) Dissociation between conflict detection and error monitoring in the human anterior cingulate cortex. *Proceedings of the National Academy of Science*, 99, 16354-9.
- Vogele, K., Bussfeld, P., Newen, A., Herrmann, S., Happe, F., Falkai, P., Maier, W., Shah, N. J., Fink, G. R., & Zilles, K. (2001) *Neuroimage*, 14, 170-181.
- Volkow, N. D., & Tancredi, L. R. (1987). Neural substrates of violent behavior. A preliminary study with positron emission tomography. *British Journal of Psychiatry*, 151, 668-73.
- Volkow N. D., Tancredi L. R., Grant C., Gillespie H., Valentine A., Mullani N., Wang G. L. & Hollister L. (1995) Brain glucose metabolism in violent psychiatric patients: a preliminary study. *Psychiatry Research*, 61: 243-53.
- Whalen P. J., Bush G., McNally R. J., Wilhelm S., McInerney S. C., Jenike M. A., & Rauch S. L. (1998) The emotional counting stroop paradigm: A functional magnetic resonance imaging probe of the anterior cingulated affective division. *Biological Psychiatry*, 44: 1219-1228.
- Widiger, T. A., Cadoret, R., Hare, R., Robins, L., Rutherford, M., Zanarini, M., Alterman, A., Apple, M., Corbitt, E., Forth, A., Hart, S., Kultermann, J., Woody, G., & Frances, A. (1996) *Journal of Abnormal Psychology*, 105, 3-16.
- Woermann, F. G., Van Elst, L. T., Koepp, M. J., Free, S. L., Thompson, P. J., Trimble, M. R. et al. (2000). Reduction of frontal neocortical grey matter associated with affective aggression in patients with temporal lobe epilepsy: an objective voxel by voxel analysis of automatically segmented MRI. *Journal of Neurology, Neurosurgery, & Psychiatry*, 68, 162-169.
- Wong M. T., Fenwick P. B., Lumsden J., Fenton G. M., Maisey M. N., Lewis P. & Badawi R. (1997) Positron emission tomography in male violent offenders with schizophrenia. *Psychiatry Research*, 68: 111-23.
- Yang Y., Raine A., Lencz T., Bihrlle S., LaCasse L. & Colletti P. (2005) Volume reduction in prefrontal gray matter in unsuccessful criminal psychopaths. *Biological Psychiatry*, 57: 1103-8.
- Yonelinas, A. P., Kroll, N. E., Quamme, J. R., Lazzara, M. M., Sauve, M. J., Widaman, K. F., & Knight, R. T. (2002) Effects of extensive temporal lobe damage or mild hypoxia on recollection and familiarity. *Nature Neuroscience*, 5, 1236-41.

Table 1. Summary of the 31 imaging studies referenced

Study	Antisocial group type	Task	Key findings (antisocial group compared with controls)
Amen, Stubblefield, Carmichael, & Thisted (1996)	Aggressive psychiatric patients	N/A	The antisocial group showed reduced rCBF in the prefrontal cortex, as well as increased rCBF in the anteromedial frontal and left temporal cortex.
Birbaumer et al. (2005)	Criminal psychopaths	Classical aversive conditioning task. The participants were asked to perform three conditioning phases (habituation, acquisition, and extinction) during which photos of faces were used as the CS and painful pressure was the US.	The antisocial group failed to show the appropriate differential activation in the amygdala, orbitofrontal cortex, insula, and anterior cingulate cortex during the acquisition of fear and successful conditioning.
Dolan, Deakin, Roberts, & Anderson (2002)	Violent APD patients	N/A	The antisocial group showed reduced volume in the temporal lobe, but not the frontal lobe.
George et al. (2004)	Violent perpetrators with alcohol dependence	Auditory continuous performance task (CPT). The task consisted of pressing a button in response to the higher pitch of two tones while ignoring the lower one during a 30 minutes period.	The antisocial group showed decreased glucose metabolism in the right hypothalamus.
Goyer, Andreason, Semple, & Clayton (1994)	APD patients	Auditory CPT.	The antisocial group showed no glucose metabolism difference in the frontal cortex. However, metabolism of the orbitofrontal, anterior medial frontal, and left anterior frontal cortices was negatively correlated with aggression.
Hirono, Mega, Dinov, Mishkin, & Cummings (2000)	Violent patients with dementia	N/A	The antisocial group showed reduced rCBF in the left anterior temporal, bilateral dorsofrontal and right parietal cortex.
Intrator et al. (1997)	Psychopaths	Lexical decision task. The task required the participants to determine whether a string of letters flashed on a screen was a real word or a non-word. The letters had neutral or affective contents.	The antisocial group showed increased rCBF in the frontotemporal regions during viewing of affective letters.

(Continues)

Table 1. (Continued)

Study	Antisocial group type	Task	Key findings (antisocial group compared with controls)
Juhasz, Behen, Muzik, Chugani, & Chugani (2001)	Violent patients with epilepsy	N/A	The antisocial group showed reduced glucose metabolism in the frontal and temporal lobe. In addition, the metabolism of the bilateral medial frontal and left temporal lobes was negatively correlated with aggression.
Kiehl et al. (2001)	Criminal psychopaths	Affective memory task. The participants were asked to memorize, rehearse, and recognize words that were emotionally positive, negative, or neutral.	The antisocial group showed decreased affect-related activity in the amygdala/hippocampal formation and the cingulate cortex, as well as increased activity in the frontotemporal cortex.
Kiehl et al. (2004)	Criminal psychopaths	Lexical decision task. During a series of 30 second blocks in which 15 letter stimuli were randomly presented, the participants were asked to identify the letter that was a real word.	The antisocial group failed to show the appropriate neural differentiation between abstract and concrete stimuli in the right anterior temporal gyrus and surrounding cortex.
Kumari et al. (2006)	Violent APD patients	'n-back' task. Monitoring locations of dots on the screen, the participants were required to press the button corresponding to the correct location of the current or previously presented stimulus.	The antisocial group showed decreased activity in the left frontal gyrus and anterior cingulate cortex.
Kuruoglu, Arikan, Vural, & Karatas (1996)	APD patients with alcohol dependence	N/A	The antisocial group showed reduced rCBF in the frontal cortex.
Laakso et al. (2000)	Violent APD patients with type 2 alcoholism	N/A	The antisocial group showed reduced volume in the right hippocampus compared with healthy controls. However, no difference was found when compared with type 1 alcoholic controls.
Laakso et al. (2001)	Violent APD offenders with type 2 alcoholism	N/A	The volumes of the posterior hippocampus were negatively correlated with the subjects' degree of psychopathy.
Laakso et al. (2002)	Violent APD patients with type 2 alcoholism	N/A	The antisocial group showed significantly reduced volume in the left dorsolateral, orbitofrontal, and medial frontal cortices. However, the findings were abolished after controlling for alcoholism.

Müller et al. (2003)	Criminal psychopaths	Emotional processing task. The participants were asked to passively view pictures with positive, negative, or neutral emotion.	The antisocial group showed reduced activation in the right temporal and parahippocampal gyrus, as well as increased activation in the right prefrontal cortex during viewing of negative pictures.
Raine et al. (1994)	Murderers	CPT. Single digits (0–9) were presented continuously on the screen and the participants were asked to press a button each time that the digit 0 was detected.	The antisocial group showed reduced glucose metabolism in the lateral and medial prefrontal cortex.
Raine, Buchsbaum, & LaCasse (1997)	Murderers	CPT.	The antisocial group showed reduced glucose metabolism in the prefrontal cortex, superior parietal gyrus, left angular gyrus, and corpus callosum. They also found abnormal asymmetries of activity (right > left) in the amygdala, thalamus, and medial temporal lobe.
Raine, Lencz, Bihrlé, LaCasse, & Colletti (2000)	APD patients	N/A	The antisocial group showed significantly reduced GM volume in the prefrontal cortex.
Raine et al. (2001)	Violent offenders	Working memory task. A sequence of familiar objects was presented on the screen and the participants were asked to press a button when a previously seen object was presented.	The antisocial group showed reduced activation in the right hemisphere, especially in the right temporal cortex.
Raine et al. (2003)	APD patients with psychopathy	N/A	The antisocial group showed increased callosal volume and length, as well as reduced callosal thickness.
Raine et al. (2004)	Unsuccessful psychopaths	N/A	The antisocial group showed an exaggerated anterior hippocampal volumetric asymmetry (right > left).
Schneider et al. (2000)	APD patients	Differential aversive classical conditioning task. The participants were asked to perform 3 conditioning phases (habituation, acquisition, and extinction), during which photos of faces were used as the CS and aversive odor was used as the US.	The antisocial group showed increased differential activation in the amygdala and dorsolateral prefrontal cortex during acquisition.

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Table 1. (Continued)

Study	Antisocial group type	Task	Key findings (antisocial group compared with controls)
Soderstrom, Tullberg, Wikkelseo, Ekholm, & Forsman (2000)	Violent perpetrators	N/A	The antisocial group showed reduced rCBF in the right angular gyrus and medial temporal gyrus, bilateral hippocampus, and left prefrontal cortex. The antisocial group showed reduced rCBF in the orbitofrontal cortex, left temporal cortex, and left hippocampus.
Soderstrom et al. (2002)	Violent offenders	N/A	
Sterzer, Stadler, Krebs, Kleinschmidt, & Poustka (2005)	Violent patients with CD	Emotional processing task. The participants were asked to passively view neutral or strong negative affective pictures during a 16.2 minute period.	The antisocial group showed decreased activation in the right dorsal anterior cingulate cortex during viewing of negative pictures.
Volkow & Tancredi (1987)	Violent psychiatric patients	N/A	The antisocial group showed decreased glucose metabolism in the frontal and left temporal regions.
Volkow et al. (1995)	Violent patients with APD or IEB	N/A	The antisocial group showed decreased glucose metabolism in the prefrontal and medial temporal regions.
Woermann et al. (2000)	Violent patients with TLE	N/A	The antisocial group showed reduced GM volume in the left anterior frontolateral and posterior frontal regions.
Wong et al. (1997)	Violent offenders with schizophrenia	N/A	The antisocial group showed reduced glucose metabolism in the anterior inferior temporal cortex.
Yang et al. (2005)	Unsuccessful psychopaths	N/A	The antisocial group showed reduced GM volume in the prefrontal cortex.

CS—conditioned stimulus; US—unconditioned stimulus; PD—personality disorders; APD—antisocial personality disorder; IEB—intermittent explosive behavior; CD—conduct disorders; TLE—temporal lobe epilepsy; rCBF—regional cerebral blood flow.