BRAIN IMAGING RESEARCH ON VIOLENCE AND AGGRESSION: PITFALLS AND POSSIBILITIES FOR CRIMINAL JUSTICE

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Introduction: Approaching the intersection of law and neuroscience

During the 2009 sentencing hearing for convicted rapist and murderer Brian Dugan, an expert witness for the defense testified on two points regarding Dugan's ability to control his violent impulses. The expert described results from clinical interviews indicating that Dugan was a psychopath— a type of criminal that notoriously lack restraint, empathy, and remorse, and is far more likely to commit violent offenses than a non-psychopathic criminal (Serin, 1991, Cornell et al., 1996). The second and more contentious piece of testimony resulted from an experimental brain imaging technique known as functional magnetic resonance imaging (fMRI). The defense's expert witness, a neuroscientist, testified that the fMRI scan showed Dugan's brain had diminished levels of activity in key areas for behavior regulation and impulse control. This case was the first instance in which expert testimony of fMRI data was admitted in a U.S. criminal trial (Hughes, 2010), and now represents a landmark intersection between law and neuroscience. Does Dugan's case mark the beginning of a new era in criminal justice, in which the neurobiological fitness of the defendant will routinely influence sentencing decisions? Or is this case a premature application of brain research technology, one that will ultimately have little bearing on criminal justice in the foreseeable future? To underscore the potential impact of this issue, a recent high-profile study has shown in a hypothetical yet realistic sentencing scenario, judges issued significantly shorter sentences when testimony from a defense expert witness indicated that the criminal offender was a psychopath with measurable neurobiological abnormalities (Aspinwall et al., 2012). MRI technology continues to develop, and the scientific understanding of the neurobiological underpinnings of violence and aggression continues to deepen. It seems increasingly likely that brain-imaging results will frequently appear in the courtroom, and it is imperative that judges and other legal experts are equipped with sufficient knowledge to evaluate and interpret modern neuroimaging data.

Subtypes of aggression and their neural substrates

A key distinction for research on aggression is between "reactive" and "instrumental" subtypes (Berkowitz, 1989). Reactive aggression is an impulsive, anger-laden response, immediately following some type of provocation (e.g., a bar fight triggered by an insult). By contrast, instrumental aggression is pre-meditated and goal-oriented (e.g., battering a potential witness to intimidate them into withholding testimony). Different mental disorders are associated with increased risk for each type of aggression. Post-traumatic stress disorder and schizophrenia, for example, are associated with increased risk for reactive aggression (Vitiello et al., 1990, Sullivan and Elbogen, 2013). Notably, psychopathy is the only disorder known to confer increased risk for both reactive and instrumental aggression (Cornell et al., 1996). Given that reactive and instrumental aggression can be differentially affected in mental health disorders, it makes sense that somewhat separable neural systems subserve these behaviors (see White, Meffert & Blair, Science in the Courtroom Vol. 1, No. 1). Much of the extant knowledge regarding the brain regions involved in reactive aggression comes from research involving rodents and nonhuman primates. Animal research permits the use of invasive techniques, such as surgical lesions or electrical stimulation, to determine the effect on the animal's behavior of manipulating a specific brain region. These studies have shown that a number of "subcortical" regions—evolutionarily ancient structures located deep in the brain—are critical for reactive aggression in animals (Figure 1). By contrast, higher-level brain areas, which serve to regulate emotional reactions, establish goals, and coordinate future behavior, may underlie instrumental aggression (Nelson and Trainor, 2007). Relative to rodents, primates—especially humans—have a much more highly developed cerebral cortex, which is the outermost layer of brain tissue. Cerebral cortex is a thin sheet of gray matter comprised of a convoluted series of bumps, called gyri, and grooves, called sulci. Regions of cerebral cortex, particularly in the frontal lobe, contain more complex aspects of cognitive control and social processing that likely serve to influence or regulate aggression (Figure 1). Animal research has provided much insight into the neurobiological basis of reactive aggression, but many uniquely human aspects of social behavior undoubtedly contribute to instrumental aggression and cannot be addressed through animal studies.

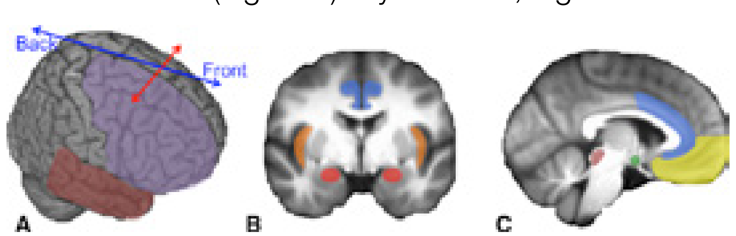

Figure 1, Brain structures involved in aggression. detailed explanation at end of article

Human brain imaging

Magnetic resonance imaging (MRI) offers a powerful means to safely and non-invasively study human brain structure and function in vivo. As such, MRI has become the predominant research tool for mapping human brain-behavior relationships. Before summarizing the insights into the neurobiology of human aggression afforded by MRI, it is first necessary to explain the basic principles of MRI technology. As the name suggests, MRI uses magnetic energy to measure brain structure or function, and utilizes the fact that different tissues in the brain have different magnetic properties. By tailoring pulses of electromagnetic fields to specific frequencies, similar to tuning a radio, MRI scanners can cause a tiny fraction of atoms in the brain to absorb some of this electromagnetic energy. Once energized, these atoms emit energy, which can be measured by the scanner and converted into an image. Because the amount of energy absorbed and emitted differs for different tissues and fluids in the brain, these different tissues and fluids appear as different intensities (i.e., lighter or darker) in the computed image. MRI can be used to create both structural and functional images of the brain (Figure 2), and structural MRI creates a static image of brain tissues. The brain's gray matter contains the bodies of specialized information processing cells, or neurons, whereas the white matter contains the wiring that links neurons together. (By analogy, regions of gray matter can be thought of as specialized computers, and white matter fibers are cables linking those computers into a greater network.) One type of structural MRI scan can be used to measure the physical dimensions of particular gray matter regions (e.g., size, shape, density), whereas another type of structural scan, known as Diffusion Tensor Imaging (DTI), can be used to measure the structural integrity of white matter pathways.

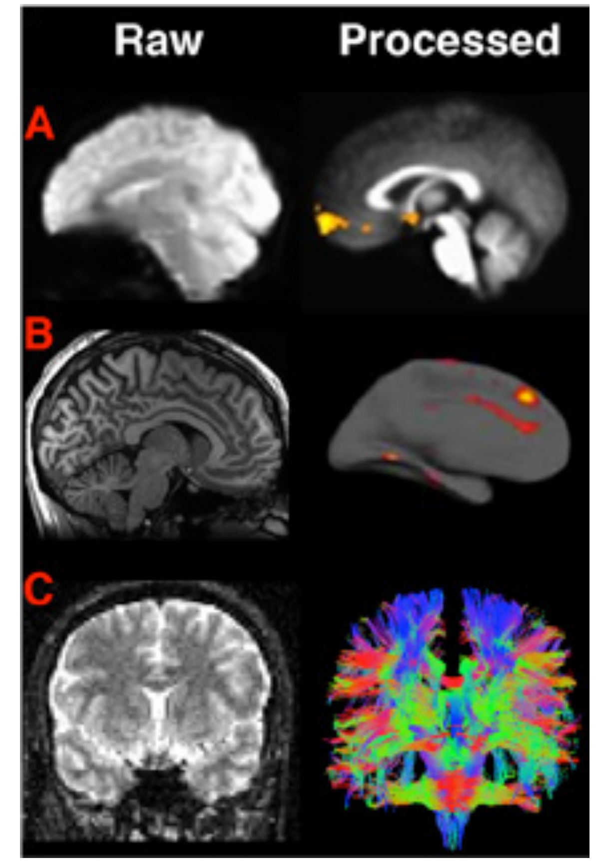

Figure 2, Different MRI modalities. detailed explanation at end of article

Unlike structural MRI, functional MRI (fMRI) provides a measure of brain activity. fMRI exploits the fact that oxygenated blood (the "fresh" blood being delivered to the brain cells) has different magnetic properties than deoxygenated blood (the "spent" blood leaving the brain cells). Hence, fMRI measures changes in the blood-oxygen-level-dependent (or BOLD) signal throughout the brain over time. Because active neurons require additional oxygen to continue firing, the brain areas showing a BOLD signal increase are presumed to be more active at that particular time. There are two basic types of fMRI, distinguished by what the research subject is asked to do during the scan; task fMRI and resting-state fMRI (rsfMRI). Task fMRI requires the research subject to complete an experimental task, such as viewing pictures, in the scanner. This fMRI allows researchers to determine which brain areas are active in response to a particular type of stimulus or during a particular cognitive process. The second type of fMRI scan, rsfMRI, requires only that the subject lie still in the scanner for several minutes with no particular stimuli or task to perform. rsfMRI is used to measure functional connectivity, or the correlation between levels of activity between different brain regions over time. Functional connectivity is presumed to reflect the degree of communication between brain regions. These structural and functional MRI techniques combined have led to recent advances in our understanding of the human neural systems underlying aggression.

Neuroimaging findings from the archetype of aggression: Psychopathy

MRI techniques applied to the study of criminal psychopaths largely corroborate findings from animal aggression research, as well as provide new insight into the neural substrates of aggressive behavior unique to psychopaths. Both functional and structural MRI studies have linked psychopathy to abnormalities in a number of cortical and subcortical areas, particularly in the frontal and temporal lobes (Figure 1, Table 1). fMRI tasks used to investigate the differences in psychopathic brain function often include viewing emotional faces or scenes, emotional learning and memory, moral reasoning, and reward processing. Psychopaths have reduced functional connectivity between the amygdala and vmPFC during rsfMRI, and reduced amygdala and vmPFC activation during moral judgment tasks. In fact, psychopathic offenders resemble neuro-

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Brain Region	*Modality*	*Summary of Finding with Respect to Psychopathy*	*Citation*
ACC	Structural	Reduced ACC volume	Boccardi *et al.*, 2011
	Structural	Cortical thinning in the left dorsal ACC	Ly *et al.*, 2012
	fMRI	Reduced ACC activation when viewing negative emotional scenes	Muller *et al.*, 2003
Amygdala	Structural	Abnormal volume in amygdala subdivisions	Boccardi *et al.*, 2011
	Structural	Decreased amygdala gray matter	Ermer *et al.*, 2012
	fMRI	Lower amygdala activity during emotional moral judgment	Glenn *et al.*, 2009
	fMRI	Amygdala activation was less predictive of ratings of severity of moral transgressions	Harenski *et al.*, 2010
	fMRI	Reduced amygdala activation when processing negative emotional words	Kiehl *et al.*, 2001
	fMRI	Increased right amygdala activation when viewing negative emotional scenes	Muller *et al.*, 2003
	Structural	Reduced amygdala volume	Yang *et al.*, 2009
	Structural	Reduced amygdala volume	Yang *et al.*, 2010
Insula	Structural	Cortical thinning in the bilateral anterior insula	Gregory *et al.*, 2012
	rsfMRI	Reduced functional connectivity between the insula and ACC	Ly *et al.*, 2012
	Structural	Cortical thinning in the left anterior insula	Ly *et al.*, 2012
	fMRI	Reduced bilateral anterior insula activity when viewing clips of emotional interactions	Meffert *et al.*, 2013
PAG	fMRI	Reduced PAG activity during a moral judgment task	Pujol *et al.*, 2012
Uncinate Fasciculus	DTI	Reduced structural integrity of the right uncinate fasciculus	Craig *et al.*, 2009
	DTI	Reduced structural integrity of the right uncinate fasciculus	Motzkin *et al.*, 2011
vmPFC	Structural	Reduced vmPFC volume	Boccardi *et al.*, 2011
	Structural	Reduced vmPFC gray matter	Ermer *et al.*, 2012
	fMRI	Reduced distinction between moral and nonmoral pictures in vmPFC	Harenski *et al.*, 2010
	rsfMRI	Reduced functional connectivity between the amygdala and vmPFC	Motzkin *et al.*, 2011
	fMRI	Increased vmPFC activity in when inferring someone else's emotional state	Sommer *et al.*, 2010
	Structural	Reduced vmPFC volume	Yang *et al.*, 2010

Table 1. Examples of MRI findings for psychopathy in brain areas involved in aggression

logical patients with vmPFC damage in a number of respects, including lack of empathy and guilt, poor decision-making, and utilitarian moral judgment (Koenigs, 2012). Psychopaths additionally show reduced functional connectivity between the insula and anterior cingulate cortex (ACC), which other studies indicate may be part of a circuit controlling goal-directed behavior. There is an emerging convergence from multiple types of MRI scans that psychopaths show abnormal structure and function in brain regions implicated in social, cognitive, and affective functions related to aggression. However, applying these data in the trial of a specific defendant presents a number of challenges.

Limitations of MRI with respect to the legal system

It is essential to recognize the fundamental limitation in causal inference when interpreting MRI data. Many are familiar with the phrase "correlation does not equal causation." MRI may reveal that certain psychopathic traits correlate with the structural or functional characteristics of a particular brain area, however, MRI cannot distinguish whether the brain characteristic causes a disorder associated with aggression like psychopathy, or vice versa (see White, Meffert & Blair, from Science in the Courtroom Vol. 1, No. 1). It is also possible that a certain brain imaging finding may not be specifically related to psychopathy per se, but may be the consequence of another condition or experience that is associated with psychopathy (e.g., drug abuse, extended periods of incarceration, head trauma, etc.). Moreover, many brain regions implicated in psychopathy underlie multiple functions. For example, the ACC is involved in affective processes such as pain, anxiety, and social attachment, but also more cognitive control processes such as error monitoring and salience detection. This is a critical consideration, as MRI evidence might be used to argue for the neurobiological basis of a defendant's social or emotional deficiency, but this type of "reverse inference" is not deductively valid. A related issue is that the brain at the time of scanning is not the same as the brain at the time of the crime; it is unlikely that the psychological state (and thus the brain state) at the time of the crime can be replicated during a subsequent MRI scan. In sum, three points regarding MRI data and causality should be kept in mind: (i) brain abnormalities can be both antecedent and consequent of behavior, (ii) a mental state cannot necessarily be inferred from brain activity, and (iii) brain characteristics during a trial do not necessarily reflect brain characteristics at the time of the crime.

A second limitation to consider is the error rate of MRI. The Daubert standard requires judges to consider the known or potential error rate of a technique when determining the validity of scientific testimony. Regarding MRI, there are two potential sources of error to consider: (i) the error rate inherent in statistical data analysis, which is the risk of falsely concluding that a relationship exists between two variables, and (ii) measurement error, corresponding to "noise" in the MRI data. When researchers compare two groups of individuals to test if they statistically differ, they select a numerical threshold as the definition of a "significant difference." This threshold (known as alpha) indicates the likelihood that a researcher will detect a statistical difference between two groups of participants when there is no actual difference (in other words, the probability of a false positive). The commonly accepted value for alpha in the field of brain imaging research is 5%, which may be higher than what is required by the Daubert standard. It is also important to note that scientific findings are often based on the comparison of two groups of individuals that systematically differ in some way, such as in the diagnosis of psychopathy, but MRI evidence in court will generally be concerned with the results of a single individual. In a study that finds that psychopaths have, on average, reduced amygdala-vmPFC functional connectivity relative to non-psychopaths, there may still be a subset of non-psychopaths with lower amygdala-vmPFC connectivity than a subset of the psychopaths (Figure 3; Motzkin et al., 2011). The alpha value a researcher chooses determines the amount of overlap that the two groups can have while still being considered "significantly different" (in a statistical sense). In addition to the statistical error inherent to alpha values, the measurement error specific to MRI must be considered in a Daubert hearing. Sources of measurement error can include technical factors such as electrical component quality and scan parameters, as well as subject factors such as head motion during scans. Because even a few millimeters of head motion during an fMRI scan can produce significant changes in the measured levels of BOLD activity, the cooperation of the subject is of paramount importance for collecting valid MRI data.

Although the extensive caveats and precautions regarding MRI techniques might give the impression that MRI is not likely to have any significant impact on the criminal justice system, we see several exciting potential applications. First and foremost, as MRI findings yield a deeper understanding of the neurobiological substrates of empathy, morality, aggression, and behavioral control, this knowledge may aid in developing more effective treatments for psychopathy. Pharmacological treatments for psychopathy may grow out of the identification of dysfunctional brain regions and the characterization of molecular profiles within those regions. MRI findings may also be used to tailor psychotherapies and cognitive exercises to improve function in disordered areas of the psychopathic brain. Improving risk assessment is another potential application of MRI. Such brain-related measures could combine with psychological or behavioral measures such as the PCL-R (otherwise known as the Psychopathy Checklist) to predict future behavior and/or treatment efficacy. Such neuro-prediction methods will likely require years of research and verification until they can be used with the reliability necessitated by the criminal justice system, but one recent study has already demonstrated improved re-arrest predictions from behavioral measures by supplementing the standard prediction algorithm with fMRI data (Aharoni et al., 2013).

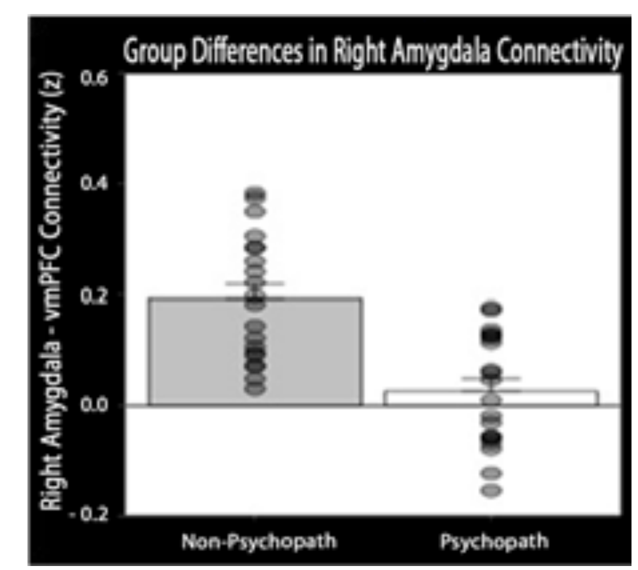

Figure 3, Inferences from group differences. detailed explanation at end of article

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Conclusion

We have provided here a brief primer on brain imaging research on violence, aggression, and psychopathy as it relates to criminal justice. At present, there are a number of features of MRI research that appear to limit the applicability of this method in the courtroom; these limitations include a need for greater replication of results, unacceptably high measurement and statistical error rates, and the lack of causal inference. However, as refinements in brain imaging technology continue to yield a clearer picture of the neurobiological mechanisms underlying human criminal behavior, attempts to use such data to influence the outcomes of criminal trials will only grow more frequent. Advances in this area of research will also likely yield improved methods for risk assessment and potentially more effective treatment options for criminal offenders. A well-informed and neuroscientifically-literate judiciary will be a critical safeguard to ensure the prudent use of these data in the courtroom.

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Figure 1. Brain structures involved in aggression.

The frontal lobe (purple) is involved in impulse control and decision-making, and the temporal lobe (maroon) is involved in more basic aspects of emotion. The red arrow shows the plane of the slice in panel B and the blue arrow shows the plane of the slice in panel C. B) A cross-section through the plane running right to left in the brain. Damage to the amygdala (red) reduces aggression in rodents and impairs emotion processing in humans. The insula (orange) is important for emotional experience and perceiving physiological responses to emotional stimuli, such as heart rate changes, and thus plays a role in both empathy and behavioral inhibition. Damage to the anterior cingulate cortex (ACC; blue) in monkeys causes reduced attention to social stimuli in order to pursue a goal; reduced attention to social cues likely plays a role in psychopaths' increased risk for instrumental aggression. C) A mid-line cross-section through the plane running back to front in the brain. The ACC is depicted again in blue. The periaqueductal gray (PAG; maroon) controls reflexive social and emotional behaviors. PAG damage in rodents decreases aggression. Damage to the hypothalamus (green) also reduces aggression in rodents. Damage to ventromedial prefrontal cortex (vmPFC; yellow) in monkeys reduces social grooming, increases aggression in dominant males, and reduces fear responses to frightening stimuli. vmPFC damage in humans produces emotional blunting, impulsivity, and moral decision-making impairments similar to those seen in psychopaths.

Figure 2. Different MRI modalities.

Left column, raw MRI data; Right column, processed MRI data used for statistical tests. A) On the left is a single time point from an fMRI scan called an echo-planar image, or EPI. Brighter areas correspond to greater BOLD signal. Note the reduced signal ("dropout") in vmPFC due to the proximity of that region to the oxygen-rich nasal sinuses. On the right, a region in vmPFC (shown in yellow) that is functionally connected to the amygdala in nonpsychopathic offenders (from (Motzkin et al., 2011). Although fMRI results only have the spatial resolution of the EPI, they are usually presented superimposed on higher resolution structural MRI scans to help orient the reader. B) On the left is a high-resolution structural MRI scan known as a T1. Analysis techniques that use T1s predominately quantify shape and structure of gray matter (the darker gray regions). On the right is a cortical thickness analysis from (Ly et al., 2012) showing regions of thinner cortex in psychopaths, including the ACC. C) On the left, a raw DTI scan used to measure properties of white matter. On the right, a three-dimensional tractography map showing a subset of the white matter fibers in the brain. The map is color coded such that fibers running left to right are red, front to back are green, and top to bottom are blue. Tractography maps are used to make inferences about the density of fibers within particular tracts, the organization of tracts, and the structural integrity of white matter.

Figure 3. Inferences from group differences.

A figure from (Motzkin et al., 2011) showing rsfMRI functional connectivity strength between the vmPFC and right amygdala in nonpsychopathic and psychopathic offenders. The bar graph underlay shows that nonpsychopathic offenders, as a group, have higher vmPFC-amygdala functional connectivity than the psychopathic group. However, the scatterplot overlay shows that the distributions of functional connectivity strengths in the two groups overlap, making it impossible to unambiguously categorize a novel individual score as psychopathic or nonpsychopathic.

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