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Applications of Neuroscience in Criminal Law: Legal and Methodological Issues

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Abstract The use of neuroscience in criminal law applications is an increasingly discussed topic among legal and psychological scholars. Over the past 5 years, several prominent federal criminal cases have referenced neuroscience studies and made admissibility determinations regarding neuroscience evidence. Despite this growth, the field is exceptionally young, and no one knows for sure how significant of a contribution neuroscience will make to criminal law. This article focuses on three major subfields: (1) neuroscience-based credibility assessment, which seeks to detect lies or knowledge associated with a crime; (2) application of neuroscience to aid in assessments of brain capacity for culpability, especially among adolescents; and (3) neuroscience-based prediction of future recidivism. The article briefly reviews these fields as applied to criminal law and makes recommendations for future research, calling for the increased use of individual-level data and increased realism in laboratory studies.

Keywords Law and neuroscience · Concealed information test · Control question test · P300 · ERP · fMRI · Development · Recidivism · Courts · Crime

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Introduction

While the study of neuroscience has been prominent in the scientific community for well over 100 years, the application of neuroscience to the law is relatively recent. Legal scholarship noting the potential relevance of neuroscience to the law only began to appear around 2000 [1], and the use of neuroscience in the courtroom has occurred even more slowly. Recently, however, the field has become increasingly mainstream. For example, in a 2010 landmark Supreme Court decision holding that juvenile criminal defendants cannot be sentenced to life without parole for committing non-homicide offenses, the Supreme Court relied in part on neuroscience research demonstrating that parts of the juvenile brain important in cognitive control of behavior are continually developing through late adolescence, thus reducing culpability of adolescent acts [2•]. Around the same time, two companies began marketing fMRI-based lie detection services, and in 2010, the first federal court admissibility hearing regarding such a test was held [3•]. These two examples are among the most prominent direct applications of neuroscience to the law, but scholars have been noting (and courts have occasionally been applying) several other uses over the course of the past decade.

The application of neuroscience to the law should not be surprising. As the chief purpose of the law is to guide behavior in ways that are socially useful, it seems obvious that neuroscience—which seeks to understand the mechanisms of the brain (the foundation of behavior)—should be of aid to the law [4, 5]. Application of scientific data and concepts to the law is not a new notion; social sciences that seek to understand and predict behavior have long been influential on the law. Psychology, for example, has provided an understanding of cognitive biases that can influence judges and jurors and led to intervention to limit those biases, sociology has influenced our framework of criminal punishment, and perhaps most influentially, incorporation of economic principles has strongly

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shaped fundamental legal rules in broad areas such as torts and antitrust. Neuroscience likewise has a number of potential contributions to make to the law.

Neuroscience is likely to be especially helpful to *criminal* law because neuroscience is, in many ways, a study of the mind, and mental states are of central importance in criminal law. In most areas of criminal law, an individual cannot be held responsible for an offense unless the prosecution demonstrates that the suspected offender (1) committed some voluntary act or omission that is unlawful (termed "actus reus"; Latin for "guilty act") and (2) committed that voluntary act with the requisite intent or mental state (termed "mens rea"; Latin for "intending mind"). Criminal laws often require one of four possible mental states: purposeful, knowing, reckless, or negligent [6]. Thus, in addition to determining what physical acts occurred, jurors in criminal cases must become amateur mind readers, deciding, based on the limited evidence available to them, whether the defendant had a sufficiently guilty mind [7].

Can neuroscience be of some help in making determinations of *actus reus* and *mens rea*? I think the answer is yes, though currently only in limited ways, but as neuroscience—an extremely nascent field—grows, its potential applications to the law, especially criminal law, are great. In this article, I will discuss three primary ways in which neuroscience is likely to aid criminal law, both during litigation itself and by more broadly shaping legal policy.[1] First, neuroscience may be used in what I loosely call "credibility assessment," a term that I use to refer to both neuroscience-based *lie* detection and neuroscience-based *memory* detection. Though neuroscience-based credibility assessment is relatively new, its potential is vast. Neuroscience-based credibility assessment, if accurate and reliable, could be used to provide evidence to legal decision makers regarding both *actus reus* and *mens rea*, as discussed below. Second, neuroscience can provide insight into individuals' *capacity* for particular mental states. Neuroscience research regarding adolescent brain development is highly relevant to law because it provides information about minors' capacities for cognitive control, which could influence criminal culpability. Last, neuroscience could potentially influence criminal law by predicting recidivism. Two of the primary justifications for punishment of criminal offenders are rehabilitation and incapacitation; to the extent that we can predict the likelihood of repeat offending, we can better tailor legal decisions to meet these ends.

Several important themes will persist through these applications. First, neuroscientists must understand that non-scientists will often overstate the applicability of narrow results and fail to see the limitation of individual studies. Lawyers serve as advocates for their clients and, if using neuroscience to aid their case, will likely argue for the broadest possible interpretation of that neuroscience. Additionally, judges and jurors may struggle in understanding and interpreting science evidence, though judges are likely to at least make efforts to directly assess the merits of the science in their admissibility decisions [11–13]. Though our knowledge of how non-scientists in the court will interpret scientific data is still limited, neuroscientists must be vigilant to explain in their papers the limitations of their studies to help reduce mischaracterizations of their work.

Second, while neuroscience may be able to offer insight as to individuals' mental capacities and mental states, the relevant mental state for legal purposes is often one that occurred in the past, at the time of the relevant conduct (i.e., at the time a crime was committed). For example, if neuroscience was, at some point in the future, able to assess whether an individual was acting with intent to harm another individual when committing a certain action, that ability would be most useful if we could test the individual *during* his crime—not a likely possibility in the relatively near future. Neuroscience's ability to tell us something about the brains of criminal defendants is likely to only help the law, in an applied sense, if it can tell us something relevant about post-crime mental states, and this limits the use of neuroscience in criminal assessments [14].

Third, while neuroscientists tend to measure effects across large *groups* to maximize power to be able to detect small effects to a high level of confidence, many potential legal applications of neuroscience require inferences made at the *individual* level. This problem has recently been focused on by several legal scholars and has been termed the "G2i" (group-to-individual) problem [15••]. While the problem may seem to be difficult to resolve, it is important to keep in mind that science used in the court may not require the same level of certainty that traditional science does (i.e., 95 % confidence that results are not due to chance), and thus, even if individual measures are noisier and less predictive than would be appropriate for scientific publication, they may still be probative and helpful in court.

Neuroscience-Based Credibility Assessment

Over the past 25–30 years, neuroscientists have begun attempting to use brain activity to aid in the assessment of credibility of individuals, particularly those involved in the commission of a crime. They have done this primarily through the use of two methods: (1) neuroscience-based lie detection, which attempts to measure whether an individual is telling the truth in response to a single question or set of questions [16, 17•], and (2) neuroscience-based memory detection, which seeks to determine whether an individual possesses knowledge of specific details of a crime or other event [18•, 19]; for

[1] This is, of course, not a comprehensive list, given the limited space here. Many other possible applications have been documented by others. For comprehensive reviews, see, e.g., [4, 8, 9••, 10].

overview, see [20•]. Both methods have been the subject of substantial neuroscience research, and individuals have attempted to admit both methods in court, though with little success to date. In this section, I will (1) briefly describe the two methods, (2) outline the recent response to the methods in the legal community, and (3) describe recent neuroscience research in the area and propose areas for further work, with an eye for the goal of increasing the applicability of the methods to criminal law.

Though they can both be used to connect an individual with a crime, neuroscience-based lie detection and neuroscience-based memory detection are two vastly different techniques, employing different sets of assumptions. Neuroscience-based lie detection typically employs some form of the Control Question Test (CQT), which poses two types of critical question to the subject: relevant questions, which are germane to the subject of investigation (e.g., "Did you shoot your wife on the night of September 16th, 2004?"), and control questions, which are deliberately vague questions about past actions that relate to the complementary relevant question (e.g., "Prior to September 16th, 2004, had you ever hurt anyone?"). Control questions are designed such that nearly any honest examinee's truthful answer would be "yes," but the examinee is led to believe, through interrogation, that he should be able to answer with a "no." It is thus assumed that the examinee is lying to the control questions, which are then compared with the relevant questions using some physiological indicator (in the case of neuroscience-based tests, often the fMRI BOLD signal) [21, 22]. Neuroscience-based lie detection tests can potentially answer questions about both *mens rea* and *actus reus*; examiners can inquire as to whether an individual physically participated in criminal conduct, in addition to whether he or she did so with the requisite criminal intent.

Neuroscience-based memory detection using the Concealed Information Test (CIT) operates using an entirely different framework. The CIT presents subjects with several items, one of which is a crime-related item (the *probe*, such as the gun used to commit a murder). Other stimuli consist of control items that are of the same category (*irrelevants*, such as other potentially deadly weapons: a knife, a bat, etc.) such that a person without knowledge of the event in question would be unable to discriminate them from the probe. If the subject's physiological response is greater for the probe item than for irrelevants, then some knowledge of the crime or other event is inferred [22]. Researchers have conducted the CIT using two types of neuroscience measures: the P300 event-related potential (ERP) component, which is large when an individual recognizes an item as meaningful among a list of non-meaningful items, and the fMRI BOLD signal, finding increased activation in frontal and limbic areas (such as the cingulate gyrus and the superior frontal gyrus) when subjects recognize meaningful items [23]. Neuroscience-based memory detection tests serve primarily to aid in determining *actus reus*; an individuals' knowledge of details regarding criminal acts provides circumstantial evidence implying that the individual committed those acts, or was somehow otherwise involved.

As research has progressed regarding these two tests, individuals have occasionally attempted to use them as evidence in American courts, both at the state and federal level. In the American court system, expert testimony offered by a party in either a civil or criminal case must be evaluated by the judge as to its reliability. If the judge finds the evidence to be reliable, he may admit the evidence, and the expert may testify before the jury. In all federal and most state courts, the judge assesses reliability under Federal Rule of Evidence 702 and the *Daubert* standard, derived from the U.S. Supreme Court's opinion in *Daubert v. Merrell Dow Pharmaceuticals*. Under that test, the judge must evaluate four factors to determine reliability: (1) "whether [the theory or technique] can be (and has been) tested," (2) "whether the theory or technique has been subjected to peer review or publication," (3) "the known or potential rate of error," and (4) the "general acceptance" of the technique [24•]. A minority of state courts use a different standard, based on *Frye v. United States* [25], which requires that expert evidence "must be sufficiently established to have gained general acceptance in the particular field in which it belongs" in order to be admissible—the test from which the fourth *Daubert* factor was derived.

Several courts have now dealt with the admissibility of neuroscience-based credibility assessment tests under both of these standards. The most prominent case in this arena is *United States v. Semrau*, a federal case in which a defendant accused of submitting fraudulent health insurance claims hired Cephos Corporation (http://www.cephoscorp.com) to demonstrate that he was not being deceptive in making statements denying his guilt. The court ruled the evidence inadmissible for several reasons, but the chief concern was with regard to the potential error rate of the test: "[T]here are no known error rates for fMRI-based lie detection outside the laboratory setting, i.e. in the 'real-world' or 'real-life' setting"[3•].[2] One other court has also rejected a Cephos test for a different reason, holding that lie detection evidence invades the province of the jury (which serves as the determiner of credibility at trial) and thus cannot be admitted [27].[3] A test conducted by Cephos's primary competitor, No-Lie MRI (http://www.noliemri.com/), was rejected in a state criminal murder case (using the *Frye* standard) on the basis that there was "no quantitative analysis of [the] procedure" [28].

[2] A Federal Court of Appeals eventually affirmed the lower court ruling on similar grounds [26].

[3] That court applied the *Frye* test, though its ruling was not ultimately related to general acceptance.

Neuroscience-based memory detection has not yet undergone the same level of judicial scrutiny. Only two cases have dealt with the admissibility of such testing, and both involved tests conducted by Brain Fingerprinting (www.brainwavescience.com), a company offering a variant of the CIT that has not undergone substantial peer review.[4] The first of those cases was *Harrington v. State*, a criminal appeal in which a defendant previously convicted of murder challenged his conviction in part by attempting to admit a Brain Fingerprinting test to show that he did not possess knowledge of details related to the murder [31]. While an Iowa District Court accepted that the P300 ERP component is a reliable marker of recognition of salient information, it was unclear as to whether it accepted the applied use of the P300 in a CIT. However, the court rejected Brain Fingerprinting's proprietary CIT methods for a lack of general acceptance in the field. A second state court has since remarked similarly [32].

Though the dearth of court rulings regarding neuroscience-based credibility assessment research makes it difficult to project the future of these tests in court, a number of legal scholars have weighed in with more substantial assessments of the tests' merits and shortcomings relevant to admissibility. Early pieces recognized the potential for neuroscience-based credibility assessment to be extremely relevant in the courtroom and potentially damaging to the legal system if admitted before being properly vetted in the neuroscience community [33, 34]. More recent articles have pointed to, in more detail, some of the same issues raised in the courts above. Roughly four major hurdles to admissibility have been discussed: (1) external validity, (2) detection at the individual level, (3) potential overweighting of the evidence, and (4) usurpation of the jury's role.

First and, in my view, most importantly, neuroscience-based credibility assessment research to date suffers from a severe lack of external validity. Because the majority of neuroscience-based credibility assessment research has involved artificial lab scenarios, such as mock-crime or instructed-lie paradigms [22, 35–37], there is no known rate of error for courts to assess, and it is difficult for them to ascertain the potential rate of error [20•]. This is critical as at least the P300-based CIT arguably satisfies or at least comes close to satisfying the other three *Daubert* factors (testability, peer review, and general acceptance). There are good reasons to think that the efficiency of these tests may be different in the field than it is in the lab. With regard to fMRI-based lie detection, many brain structures implicated in deception are involved in executive control—the underlying theory being that lying is cognitively more difficult than truth telling and thus involves recruitment of brain areas responsible for such high-level cognitive control. However, lies outside of the laboratory may be more carefully and thoroughly rehearsed, and thus detection rates could be reduced because producing those lies during the test may require less cognitive control [38–41]. And with regard to the P300-based CIT, most controlled mock-crime studies only present stimuli based on clearly encoded, central details, in which no distracting information occurs alongside the mock crime—a stark contrast from the detection of real-world knowledge, which may be more difficult to detect [20•].[5]

Second, many fMRI-based CQT studies to date suffer from the G2i problem at two levels: first, many studies report only group analyses or individual analyses that required the use of a model-building group [38], and second, studies that report individual detection rates often still use a form of "group analysis" by detecting whether individuals are being deceptive across an entire block featuring many different deceptive responses [e.g., 46–48]; for other cites, see [38]. These studies, unfortunately, tell us little about whether deception in response to a single question can be detected. While at least two studies do report data at the individual-event level, finding accuracy rates of 78 and 88 %, replication is badly needed [17•, 49]. The G2i issue is not as present in the P300-based CIT literature, which has long reported individual detection rates for recognition of single items [e.g., 18•, 19, 22, 50•].

Third, there is some concern that if neuroscience-based credibility assessment evidence were to be admitted, it would be so powerful in the minds of judges and jurors that its use could be problematic. Federal Rule of Evidence 403 allows a judge to reject evidence "if its probative value is substantially outweighed by a danger of…unfair prejudice." The rule gives great discretion to the trial judge to evaluate both the probative value and prejudicial potential of the evidence, and so rulings based on Federal Rule of Evidence 403 will be difficult to predict and potentially unique from case to case; still, some scholars have argued that the rule could bar neuroscience-based credibility assessment evidence [51, 52].

Fourth, and relatedly, some courts have shown a concern that credibility assessment evidence tramples on the role of the jury, which serves as the sole assessor of witness credibility [27, 53]. There is some legal literature arguing that this standard makes little sense if the jury is less competent at credibility assessment than a technological tool, such as a lie detector, though determining whether this is the case is a

[4] The "Brain Fingerprinting" variant of the P300-based CIT, commercialized by Lawrence Farwell, is controversial and has received significant criticism in the field [29, 30].

[5] Once error rates are identified based on studies with a high level of external validity, it is not clear what rate of error would be considered low enough to allow for admissibility. Some legal scholars have noted that neuroscience-based credibility assessment techniques appear to have a relatively low rate of error compared to forensic evidence (which is often admitted in court despite potentially high error rates) and may even have a low error rate compared to jurors, who may have difficulty making accurate determinations of the veracity of witnesses' statements [42–44]; for contrasting view, see [45]. More research is necessary before these comparisons can be made with any confidence.

difficult endeavor [20•, 42, 54]. It is critical to recognize, however, that while neuroscience-based lie detectors undoubtedly assess the credibility of witnesses, memory detectors do not serve the same function; they instead assess whether information is present (much like fingerprint evidence) and make no claim regarding the veracity of statements—a nuance that is missed in some of the legal literature [e.g., 55].[6]

In addition to these evidentiary concerns, there are also constitutional issues that may limit the use of neuroscience-based credibility assessment in criminal contexts. Two Amendments pose potential problems: the Fourth Amendment, which protects an individual from "unreasonable" government searches and seizures [57], and the Fifth Amendment, which protects an individual from being "compelled in any criminal case to be a witness against himself" [58]. Over the past 5 years, legal scholars have begun to explore these topics, though the literature is still relatively small. The Fourth Amendment concerns likely pose less of a problem for police investigations: scholars have focused on the fact that individuals may have a reasonable expectation of privacy in the their brain waves, even though they can be measured outside of the skull itself, and thus may be protected from warrantless searches under current Fourth Amendment doctrine [59, 60•]. This issue would likely become a moot point in most criminal investigations, however, as police seeking to use neuroscience-based credibility assessment on criminal defendants would very likely have the probable cause necessary to secure a warrant for the search.

Of greater threat to the use of neuroscience-based credibility assessment in criminal investigations is the Fifth Amendment. As a general matter, the Supreme Court has distinguished between the examination of bodily samples, which can be compelled without violating the Fifth Amendment, and communicative acts or statements, which are protected [59]. It is an open question as to whether neuroscience-based lie detection or neuroscience-based memory detection paradigms would be considered as eliciting "communicative acts" that would be considered testimonial, or merely eliciting physical brain responses that are unprotected. Some scholars have argued that the current dichotomy between physical information and communicative statements does not sufficiently account for brain-based evidence and will need to be revised if this issue eventually comes before the courts [59, 61, 62].[7] Clearly, this is a novel area of legal analysis that requires further thought and writing.

Though the above discussion paints a relatively gloomy picture regarding the potential use of neuroscience-based credibility assessment evidence in court, some recent work has improved the ecological validity issues that limit most neuroscience-based credibility assessment research. Two groups have begun attempting to detect recognition of information acquired incidentally in real-world, everyday life situations, rather than information acquired through instructed mock crimes committed in artificial lab scenarios. One recently published P300-based CIT study involved subjects carrying a small video recording device during a normal day, which was later used to generate a CIT attempting to detect recognition of specific details encountered by the subjects while wearing the camera [50•]. Though only an initial attempt, the results were promising: there was perfect discriminability between those subjects who were shown information relating to their daily activities and those who were not. Anthony Wagner and colleagues are currently pursuing a similar project using fMRI data as the dependent measure [66]. Other groups have recently focused on CIT variants that could be useful outside the courtroom by providing investigators with valuable information: three recent studies have applied the CIT to detect information learned through the planning of a mock terrorist attack, applying a "searching" CIT method in which investigators use the CIT on individuals already known to be involved in the planning of a crime in order to determine the location or time of a planned mock attack [22, 67, 68].[8] Last, some recent work has focused on assessing the effects of a time delay between the acquisition of crime-related knowledge and the testing for recognition of that knowledge [69, 70]. While neuroscience-based credibility assessment undoubtedly faces hurdles before it can be significantly useful in the U.S. legal system, these studies have begun to advance the field toward greater ecological validity, a critical step if these tests are to be used in court.

Neuroscience Informing Criminal Responsibility

Neuroscience can also potentially aid courts by determining whether a defendant's brain had the neurological capacity for a sufficiently culpable mental state. At the most basic level, a structural brain scan could demonstrate the capacity for a mental state by showing damage to a particular area of the brain (a tumor, for example) that is critical to cognitive control [4]. Recently, important research regarding the neurological development of adolescents has at least partially influenced broad policy changes regarding criminal punishment of minors. The core of this research has demonstrated that

[6] Though it is clear that neuroscience-based credibility assessment tests face significant hurdles before they can be admitted in court, those tests could still serve as an investigatory purpose before admissibility concerns have been addressed [56]. I note several studies attempting to pursue such uses of the CIT below.

[7] Others have argued that current doctrine resolves the issue, with some asserting that such evidence could not be compelled [63, 64] and some arguing that it could [65].

[8] Note that some of these studies use more traditional physiological measures, such as skin conductance, rather than P300 as the dependent measure.

adolescents undergo a period during which they have a greater propensity for risky behavior than during other developmental periods or adulthood [71, 72]. Though this line of research is still at its early stages, its basic neurological thesis is that areas involved in executive control and decision making (primarily prefrontal regions) develop in asymmetric timing with other major brain regions, particularly those associated with motivational and emotional responses (primarily in the limbic system). This has been termed the "imbalance model of brain development"[73] and is relevant to the law because it potentially explains, in part, adolescent propensity for risky behaviors that lead to higher levels of crime for the adolescent population as compared to other populations.

Research along these lines has likely influenced legal doctrines regarding criminal punishment of minors, though perhaps not yet at a systemic level. Two major Supreme Court cases have recently cited neuroscience research as relevant to the punishment of minors in two ways: (1) it implies that adolescents' actions are "not as morally reprehensible as [those] of an adult," presumably because adolescents lack the same level of cognitive control over their risky behavior that a fully developed adult would possess [74], and (2) because the adolescents' criminal behavior is at least partially driven by a propensity for risky behavior linked to development, their "actions are less likely to be evidence of irretrievably depraved character than those of adults," and there is a greater possibility that they can be rehabilitated [74]. Thus, the Supreme Court has in part used neuroscience evidence of this type to support its holdings that life-without-parole sentences for juvenile offenders are cruel and unusual, in violation of the Eighth Amendment, for both non-homicide offenses [74] and homicide offenses [75].[9]

The implications of this reasoning are vast. Though the cases (*Graham v. Florida* and *Miller v. Alambama*) only applied to very serious punishments—life imprisonment without parole—the reasoning aiding those decisions could be theoretically applied to any level of juvenile punishment: if a juvenile is less culpable of an offense warranting extreme punishment because of his underdeveloped neural circuitry, it makes sense that a juvenile is less culpable of less severe crimes that still implicate the juvenile's propensity for risk [77]. Even more broadly, the reasoning could be applied to almost any level of biologically driven propensity for increased risk-taking behavior, whether involving adolescents or not,[10] and in a similar way, these arguments could be used to attempt to justify reduced *affirmative rights* of adolescents, e.g., age restrictions for driving, alcohol use, or even restrictions of abortion rights for minors [79].

There are good reasons, however, to be cautious in predicting that neuroscience will lead to sweeping reforms of our understanding of criminal culpability and rehabilitation. First, both *Graham* and *Miller* extended an earlier juvenile Eighth Amendment ruling, *Roper v. Simmons* [80], which held that death penalty sentences for juveniles violate the Eighth Amendment. Roper relied on similar reasoning as *Graham* and *Miller*, noting that "as any parent knows…a lack of maturity and an underdeveloped sense of responsibility are found in youth more often than in adults and are more understandable among the young. These qualities often result in impetuous and ill-considered actions and decisions" [80]. Thus, some have argued that *Graham* and *Miller* did not use neuroscience evidence to demonstrate an entirely new principle but rather used it to support a principle that was already clearly demonstrated behaviorally [81, 82].[11] Second, all of these cases involved a unique population facing extreme punishment; the legal system is not likely to extend more lenient sentencing to all other contexts in which it can be demonstrated that the defendant had a biologically based propensity for the criminal conduct.

Nevertheless, the use of neuroscience research in aiding the court's *Graham* and *Miller* conclusions may represent only a first step, and as neuroscience research regarding adolescent development progresses, it may provide stronger and more relevant information for courts to consider. Recent work has focused on the interaction between the type of stimuli or situation confronted by adolescents or adults and their ability to self-regulate or delay gratification. Studies using go/no-go (GNG) tasks have demonstrated that while adolescents can often control impulses as well as or better than adults in *neutral* contexts, in *emotional* contexts that impulse control is severely restricted [83]. Among individuals in whom such impulse control is difficult, this effect can persist into adulthood as well [84••]—an indication that this research is not limited to applications involving adolescents.

These studies also highlight one major gap in the research in this area that I alluded to earlier—the G2i problem. While in its current state, the group research regarding the adolescent development of executive control can inform policy decisions and legal interpretation at a broad, group level (as in *Graham* and *Miller*), a much more useful measure for legal purposes

[9] It is worth noting that *Graham* and *Miller* provide a bright-line age cutoff of 18 years old only under which leniency is given in sentencing. Of course, the research does not support this specific outcome; development does not cease at exactly 18 years old and progresses slowly over time, which would support a more flexible rule [76]. Though blunt, such a strict cutoff has one great merit: it is easily administrable, something courts often seek in their rulings.

[10] For example, the same reasoning could be used to argue in favor of reduced sentences for psychopaths as diagnosed through neurological evidence [78].

[11] In addition to this, other rationales were central to the court's conclusions in *Roper*, *Graham*, and *Miller*, such as the national consensus regarding death and life-without-parole sentences among the states.

would be an index of individual development that provides some indication as to the individual's cognitive propensity for risky behavior. This is not currently available, and it is well established in the literature that there are significant individual differences between adolescents in prefrontal development [85]. There may also be legal hurdles to introducing such propensity evidence even if it is made available [86], but that concern is not yet ripe: as the research currently stands, the variability within age groups and across development is too great to allow for individual diagnostic data [71]. As noted above, however, researchers seeking to develop individual measures assessing the neurological development of areas relating to executive function and risky behavior may take some comfort in the fact that even noisy measures may be helpful in the legal context, where $p<0.05$ does not reign supreme.

Last, a substantial literature has developed regarding neuroscience's potential broader impact on criminal responsibility as a whole if our understanding of the brain eventually calls into question individuals' ability to control their actions at all; that is, neuroscience could potentially cast doubt on the entire *mens rea* and culpability concept if biological evidence indicates that our actions are bound by a series of determined physical events that necessary lead to certain behavior. This literature is broad and beyond the scope of what can be addressed here, but suffice it to say that the debate is vigorous and spans work from scholars in science [87], law [e.g., 88–90], and philosophy [91, 92].

Neuroscience Informing Punishment and Rehabilitation

Once a court has determined that a criminal defendant is legally culpable for his conduct, it must determine the appropriate punishment. There are many justifications for criminal punishment, but among the most prominent are utilitarian theories such as rehabilitation (the notion that convicts can change and become productive members of society) and incapacitation (the notion that society benefits from keeping the convict away from the general population, preventing further crime). Of course, these theories are built on the premise that convicts can be rehabilitated and that temporarily or permanently removing them from society will reduce future crime. Thus, to the extent that we could predict the likelihood of a convict being rehabilitated or his likelihood of committing future crimes (recidivism), we could impose more socially efficient punishments. Neuroscience has some potential to provide such predictions [93].

Though this area of neuroscience is relatively nascent, some recently reported data have generated significant excitement. One of the strongest behavioral predictors of recidivism is impulsivity or lack of restraint and consideration of consequences [94]. Though the relationship between impulsivity and recidivism is well studied, Aharoni et al. recently noted that such behavioral measures are simply proxies for direct measurement of brain areas responsible for inhibition [95••]. Using a GNG task, Aharoni et al. replicated prior findings that lower levels of anterior cingulate cortex (ACC; an area associated with inhibition and regulation of behavior) activity were associated with increases in commission errors in the GNG task, but also found that such increased brain activity predicted rearrest, and provided an incremental increase in predictive potential over behavioral measures alone [95••]. Though this is perhaps the most relevant new study in the area, it is the result of significant prior foundational work, and the field warrants far greater discussion than can be provided in limited space here. For an excellent recent review, see [96•].

There are, of course, limitations to the application of this research. First, as discussed above, there has been no demonstration that these effects are robust enough to be detected at the individual subject level, though some have argued that group data in this context could still be informative in making individual sentencing decisions [97]. As noted above, even if individual data were available, courts are likely to be leery of taking individual biological propensity for recidivism into account in sentencing decisions, though they may be more willing to accept this evidence in the sentencing context than in the criminal liability context [98]. Second, there may be limitations as to how much additional signal neuroscience-based measures provide over behavioral measures that are easily ascertainable in the individual case. Though Aharoni et al. and others have found some additional predictive value in the biological measures, replication and extension is necessary. Third, the legal status of using biological markers of recidivism in sentencing is questionable; the use of such methods without consent from a defendant could potentially violate the Equal Protection Clause of the U.S. Constitution, though it is likely that such uses would only need to have a "rational basis" in order to be permissible [98]. It remains to be seen how courts will handle such controversial data as the research progresses in this area and becomes more sensitive at the individual level.

Conclusion

It is difficult to predict the influence that neuroscience will have on the law because the field is so rapidly growing. As noted above, the usefulness of many applications will hinge on the ability to deal with the G2i problem, and it is too early to say whether robust group data, such as those regarding brain development related to risky behavior, will eventually lead to sensitivity at the individual level. Neuroscience-based credibility assessment is unique in this regard; much of the research there has dealt with the G2i problem, and researchers should now seek to pursue field research and externally valid laboratory simulations. Last, neuroscience researchers interested in impacting the law should seek to develop tools that provide information independent of that which can be obtained through behavioral methods, as courts will likely be leery of implementing new tools that seem to only support what could have been learned in simpler ways.

Compliance with Ethics Guidelines

Conflict of Interest John B. Meixner Jr. declares that he has no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

References

Papers of particular interest, published recently, have been highlighted as:
- • Of importance
- •• Of major importance

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