Following every well-publicized act of incomprehensible violence, the news media rush to interview neighbors, family members, and experts in an attempt to discover what could have led an individual to commit such a barbarous act. Certain stock answers are reiterated: video games, bullying, violent films, mental illness, the availability of guns, and a society that is increasingly both anonymous and callous. Might imaging be one of the more valuable keys to unlocking the mysteries of violent, aggressive people? This article explores these questions and their complex answers in the context of violent individuals.

**After completing this article, the reader should be able to:**
- Describe the fundamental attributes of violence and aggression and the scope of violence as a public health concern.
- Discuss current theories on the myriad causes of violence.
- Identify environmental stressors that can contribute to violence.
- Understand imaging's contributions toward an increased understanding of human violence.
- Explain the role of imaging in court cases involving acts of violence.
- Consider the insights imaging can lend to a discussion about possible solutions to the problem of violence.

A note was found on a coffee table in the home of 15-year-old Kip Kinkel after his arrest for a school rampage shooting:

I have just killed my parents! I don’t know what is happening. I love my mom and dad so much. I just got two felonies on my record. My parents can’t take that! It would destroy them. The embarrassment would be too much for them. They couldn’t live with themselves. I’m so sorry. I am a horrible son. I wish I had been aborted. I destroy everything I touch. I can’t eat. I can’t sleep. I didn’t deserve them. They were wonderful people. It’s not their fault or the fault of any person, organization, or television show. My head just doesn’t work right. God damn these VOICES inside my head. I want to die. I want to be gone. But I have to kill people.

I don’t know why. I am so sorry! Why did God do this to me. I have never been happy. I wish I was happy. I wish I made my mother proud. I am nothing! I tried so hard to find happiness. But you know me I hate everything. I have no other choice. What have I become? I am so sorry.

After writing this note, Kinkel waited until dawn on May 21, 1998, the day after killing his parents, then taped 2 bullets to his chest, a knife to his leg, and drove to his Oregon high school carrying firearms and 1127 rounds of ammunition. He fired 48 shots in the cafeteria in less than 1 minute, killed 2 of his fellow students, and wounded 25 others before being subdued by students who took advantage of a lull when Kinkel paused to reload. To his student captors, he said, “Just kill me.”

Kinkel’s own words and thoughts tell us why he might have taken this
course of action. He exculpates television and everyone but himself. At the same time, he writes of his peers:

*I feel like everyone is against me, but no one ever makes fun of me, mainly because they think I am a psycho. There is one kid above all others that I want to kill. I want nothing more than to put a hole in his head. The one reason I don’t: Hope. That tomorrow will be better. As soon as my hope is gone, people die.*

He also writes of his loneliness and isolation:

*I sit here all alone. I am always alone. I don’t know who I am. I want to be something I can never be. I try so hard every day. But in the end, I hate myself for what I’ve become.*

**The Search for Causes**

Was it Kinkel’s access to guns? His parents forbade violent toys in the household—there were no toy soldiers or guns in young Kinkel’s toy box. Yet, over time he wore his parents down, and for his 12th birthday he received a rifle. Kinkel’s parents took him for therapy, and Kinkel’s therapist, a gun enthusiast, talked with the boy about guns. Kinkel began a campaign for a 9-mm Glock handgun, and eventually his parents again relented—with the conditions that Kinkel pay for the gun over time, only fire it when with his father, take a gun safety class, and keep the gun under lock. Eventually, Kinkel also owned or had access to a .22 Ruger semiautomatic rifle, a 20-gauge sawed-off shotgun, a lever-action rifle, a .22 Ruger pistol, a .22 caliber handgun, and a gun his father had owned when he was a young man.

In January 2000, the Public Broadcasting Service’s *Frontline* aired “The Killer at Thurston High,” a compelling, thorough examination of Kinkel, his family, and what might have led Kinkel to kill. The documentary considers countless possible causes for Kinkel’s rampage. Kinkel might have suffered from some form of mental illness: depression or schizophrenia. His therapist prescribed Prozac, but after 3 months his parents let him stop taking the medication. Kinkel had dyslexia; could neurodevelopmental factors have contributed to the makeup of this aberrantly violent child? His parents were thoughtful, educated, responsible citizens who attempted to help their struggling son, but maybe there was a genetic component to his difficulties. Feelings of inadequacy plagued the boy; his elder sister was a star in every way imaginable, and comparison to her achievements only worsened his plight. A constellation of factors likely combined to create the young killer, a fact that seems true for all people who perpetrate violence.

Kinkel was not the first to engage in a rampage shooting of his school, and he was by no means the last. Prior to Kinkel, in 1997 a 16-year-old boy in Pearl, Mississippi, killed his mother and then went to his school, where he shot 9 classmates, killing 2 of them. Just 2 weeks later, a 14-year-old Arkansas student shot 2 students. In December 1997, Michael Carneal, a Kentucky high school freshman, wreaked carnage at his school: he killed 2 students, left 1 a paraplegic, filled the arms of a girl with bullet fragments that ended her dreams of a basketball career, and wounded several others. Mitchell Johnson and Andrew Golden—middle school students—killed 4 students and 1 teacher and wounded 10 others in Arkansas in March 1998.

Perhaps the most infamous school shooting occurred 11 months after Kinkel’s spree. Dylan Klebald and Eric Harris killed 12 students and a teacher, wounded 23 other students, and then killed themselves at Columbine High School in Colorado. The Columbine massacre literally changed the vocabulary of American culture: a Google search of “Columbine” brings up as a first result not the columbine flower but reports of the shooting.

So greatly has the Columbine event permeated American consciousness that years later others continue to idolize and emulate Klebald and Harris. For example, in North Carolina 7 years after Harris and Klebald’s bloodbath, a mentally unstable young man who idolized the Columbine shooters killed his father and then shot at fellow students until his rifle jammed. Prior to his shooting spree, the student had traveled with his mother across the country to Columbine High School and bought a black trench coat. While this Directed Reading article was being written, an Oregon teenager was charged with attempted aggrivated murder when 6 bombs he intended to detonate at his school were found in his bedroom. Reports indicate that this teen, too, was inspired by the Columbine events.

School shootings, while highly evocative of a violent turn of mind and exquisitely popular with the mass media, are not the only or most common form
of violence. The Federal Bureau of Investigation (FBI), which gathers data submitted by law enforcement agencies throughout the country, includes in its violent crime category murder, forcible rape, robbery, and aggravated assault. The most current available FBI statistics (for January-June 2012) show that violent crime as a whole decreased between 2008 and 2010; between 2011 and 2012, however, it rose 1.9% nationwide, and murder rates increased in cities of more than 500,000 inhabitants by as much as 7.2%.

The Centers for Disease Control and Prevention (CDC) also collects statistics on violence and reports that homicide is the leading cause of death for young people aged 10 to 24 years. Between 1994 and 2010, homicide rates for 10- to 24-year-olds were higher than for all other ages combined. Homicide was the second leading cause of death for 15- to 19-year-olds in 2010. Assaults brought more than 700,000 10- to 24-year-olds to emergency departments for nonfatal injuries in 2011. Violence not only leads people to emergency departments, but it also takes place at a high rate within the health care setting (see Box 1).

Violence is costly in physical, emotional, and economic terms. Society must shoulder the financial burden of the criminal justice system, including police, judges, courtrooms, jurors, prosecutors, public defenders, jails, and prisons. A 2011 study reported that violent criminal behavior consumed 11.9% of the gross national product of the United States. Another estimate of the annual economic price of criminal behavior in the United States puts the figure at $2.406 trillion. Incarceration accounts for one of the most significant costs associated with violent criminal behavior; approximately 62% of the male prison population is composed of violent offenders.

Violence also presents a public health concern, with more than 2.2 million people treated for injuries associated with violence every year to the tune of approximately $37 billion in medical expenses and lost productivity. The United States is not alone in facing the variety of costs associated with violence. Germany, for example, spends 6.5% of its gross domestic product on costs associated with violent criminal behavior. In 2002, the World Health Organization reported that worldwide, 1.6 million people died as a result of violence.

These powerful motivators drive the search for explanations about the nature of human aggression, and imaging contributes in important ways to experts’ growing knowledge about the etiologies of violence. Neuroimaging studies including magnetic resonance (MR) imaging, functional MR (fMR) imaging, positron emission tomography (PET), and single photon

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**Box 1**

**Violence in the Health Care Setting**

Violence associated with patient care, including physical assaults, is reported to be the most prevalent cause of nonfatal injury in health care organizations. Although nurses are subjected to the most assaults, other practitioners also are at risk. Violence is not limited to assaults; between 1996 and 2000, 69 homicides took place in the health services. The U.S. Department of Labor Occupational Safety and Health Administration identifies factors responsible for the increased risk of violence in the health care setting, including:

- Prevalence of handguns and other weapons among patients, their families, or friends.
- Use of hospitals for criminal holds and care of acutely disturbed, violent individuals.
- Availability of drugs and money at hospitals, clinics, and pharmacies, making them likely robbery targets.
- Unrestricted movement of the public in clinics and hospitals and long waits that lead to client frustration.
- Presence of gang members, drug or alcohol abusers, trauma patients, or distraught family members.
- Solo work, often in remote locations with no backup or way to receive assistance such as communication devices or alarm systems.
- Lack of staff training in recognizing and managing escalating hostile and assaultive behavior.
- Poorly lit parking areas.

Some states have enacted criminal statutes specifically addressing this problem. In New Mexico, for example, it is a fourth-degree felony (as opposed to a simple misdemeanor) to commit battery upon a health care worker: “Battery upon a health care worker is the unlawful, intentional touching or application of force to the person of a health care worker who is in the lawful discharge of the health care worker’s duties, when done in a rude, insolent or angry manner.”

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emission computed tomography (SPECT) provide psychiatrists, courts, and others involved in the study of violence with vital methods for exploring the problem. Emerging neuroscience discoveries not only help us better understand violent minds but also aid discussions about how the legal system might need to adapt to align itself with the science of behavior. With greater frequency, neuroscientific evidence, including imaging results, makes its way into evidence in criminal cases as attorneys gain an understanding of how such evidence might achieve a conviction, determine a defendant’s mental status, and persuade a judge or jury to reduce a sentence or a parole board to keep or release a prisoner.

A Brief History of Violence

Aggression is a natural behavior found throughout the animal kingdom; it plays an important evolutionary role in ensuring survival of the fittest and can be a means of self-preservation. Because aggressiveness promotes survival, the behavior is reinforcing and gives pleasure to the aggressor. Robert Sapolsky, a neuroendocrinologist at Stanford University’s School of Medicine, provides a concise, straightforward description of the evolutionary and personal advantages of aggression:

[If you’re going to be a savanna baboon, you probably don’t want to be a low-ranking one. You sit there for two minutes digging some root out of the ground to eat, clean it off and...anyone higher ranking can rip it off from you....Or you could be sitting there, minding your own business, bird-watching, and some high-ranking guy having a bad day decides to make you pay for it by slashing you with his canines.]

The progression of human society has lessened the importance of aggression, and for the most part violence is less necessary to survival. With some exceptions, we no longer attack the person who rams our car and injures us. We sue that person or engage in some other civilized form of mediation of our disputes. In a well-functioning society, problems are solved by means other than fists, and aggression is rendered less adaptive and more problematic for the perpetrator.

Even within recent memory, our culture’s perception of what is acceptable violence has changed. Violence that would be considered unacceptable and criminal when it takes place between strangers was once sanctioned between married persons. Male-female relationships and child-rearing practices have been greatly redefined in recent decades, and that has affected the acceptability of interspousal violence and corporal punishment. In 1965, a full 25% of male Americans surveyed approved of a husband slapping his wife. Women were not that far behind: approximately 17% of them approved of the practice. By 1995, women’s approval of a husband slapping his wife had declined to just more than 5%; men’s approval of the practice had declined but took a sharp upswing toward approval once more, climbing from 10% between 1990 and 1995 to nearly 15% in 1995.

The law, including criminalization of certain acts, tends to reflect societal changes and norms. New gender roles that came about in the 1970s largely as an outcome of the women’s movement resulted in changes in the law. A man can no longer claim the defense of “justifiable provocation” when he kills his adulterous wife or her lover; crimes of passion might make good fiction, but they are no longer condoned by the law.

Society has, for the most part, become less tolerant of violence. Perpetrators of the most serious forms of violence are ostracized, imprisoned, and sometimes put to death. Our aggressive and violent tendencies also are controlled by other human attributes including empathy, morality, and reason. On a daily basis, certain attributes help us to refrain from violence. We must exercise impulse control, tether what otherwise might be our instinct to lash out to punish, control, or vent our frustrations on another. We also must be able to anticipate the repercussions of our actions, understanding that we will ourselves be punished, that we will feel guilt or remorse about having injured another person. These abilities to exercise impulse control and anticipate repercussions—and the degree to which we are capable of exercising them—might distinguish criminally violent members of society from law-abiding, relatively more peaceful citizens.

Although society might have changed over time and violence may have become a less adaptable behavior, our chemistry and brains have not necessarily kept pace with civilization’s developments. The brains of violent individuals appear to process information related to
repercussions and results differently, and these individuals tend to manifest a flawed system of impulse control when compared with nonviolent people. Researchers examine these and other specific brain functions.

To study violence, it is first necessary to categorize and define what we mean by aggression and violence. On the most superficial, general level, aggression usually implies a threat or assault; violence refers to actions that result in physical harm. Interpersonal aggression has been defined as “overt behavior with the intent to cause damage or other unpleasantness to another person.” The other’s bodily boundary is breached, and bodily harm results. Subdivisions of violence further refine the concept, and experts recognize 2 distinct expressions of violence: affective defense and predatory attack. The former is a response to an immediate threat and involves arousal of the autonomic nervous system. Affective violence, the evolutionary basis of which is survival against an imminent threat, tends to be impulsive and emotional. Conversely, predatory, or instrumental, violence is emotionless, lacks autonomic arousal, and is premeditated, purposeful, and goal-directed, rather than simply responsive. The evolutionary basis of predatory violence is hunting and food gathering.

The presence of a psychological or physical threat arouses the fight-or-flight response, causing palpitations, sweating, trembling, and rapid breathing. Portions of the brain act to evaluate the perceived threat to ascertain whether it is a genuine threat to survival or a harmless insult. Disruptions in this evaluation process that affect the perception of a threat or the ability to assess a threat or control and calm responses to threats result in violent reactions that are neither accurate nor appropriate to a given situation. Dysfunctional control can mean that minor insults to the ego are viewed as an overwhelming threat, thus compelling a violent response.

Violence can take the form of domestic and child abuse, sexual assault, and a plethora of categories of murder, including revenge killings, rampage shootings, spree killings, serial murders, workplace violence, and violence against nonhuman animals. People who commit violent acts also come in all shapes and sizes, from all walks of life. They will, however, present with some common traits and identifying markers. Someone who engages in aggressive behaviors as a response to a misperceived threat vs justified self-defense likely will have less self-control, greater impulsivity. Such an offender can be described as having a hair trigger. Someone who acts violently with a desire to control or abuse others—a predator—likely will be deficient in empathy and have a need to seek some type of stimulation in the form of constant activity, thrill-seeking, or rebellion.

Some violent offenders such as psychopaths predominantly relate to others as prey-predator; even their primary relationships are characterized by an absence of genuine affection. Emerging evidence indicates that psychopaths could even have a predatory acuity, an ability to cull the weak animal from the flock, a heightened ability to recognize accurately fear, weakness, and distress in others. Serial killer Ted Bundy, who seemed to have an uncanny ability to choose the most vulnerable individuals as his victims and who sometimes constructed elaborate ruses to lure his victims away from any possible access to help or rescue, reportedly described himself to an FBI special agent as having progressed from impulsive, amateur kills to predatory killing (see Box 2).

A leading expert on psychopaths describes them as “intraspecies predators who use charm, manipulation, intimidation, sex and violence to control others and to satisfy their own selfish needs.” They lack empathy, flaunt social norms without guilt or remorse, and are bereft of the conscience that intercedes for most human beings. Psychopaths are manipulative, parasitic, impulsive, and need constant stimulation. Omnipresent anger causes them to aggress over small things, and the typical incarcerated psychopath has an extensive juvenile record of convictions for serious, violent crimes. Psychopaths invariably blame their victims, and the FBI calls psychopathy “the most dangerous of the personality disorders.”

The FBI presents a motivational model of murder that distinguishes between different types of murderers and their varying reasons for killing. Included within that classification system are criminal enterprise murderers (murder perpetrated for material gain), personal-cause murderers (murder due to emotional conflict), and sexual homicide (murder as part of a sexual act). Experts who studied a large group of indigent murder
defendants and death row inmates also identified stereotypical differences between people who kill one person vs those who kill several people. They reported that persons who kill more than one person are more likely to have a personality disorder and less likely to have a developmental disorder. Such murderers also are more likely to have a criminal history. By contrast, those who kill a single victim are more likely to have a developmental disorder and less likely to have a personality disorder or criminal history. According to the study’s authors, the most educated murderers tend to be those who commit sexual homicides, and those who commit personal-cause murders have the highest rate of substance abuse.

**The Birth of Violence**

**An Abundance of Theories**

Aggression is a function of brain circuits and connections within and between those regions, and when 1 or more of these brain structures or the connections between them are either structurally or functionally abnormal, the likelihood of impulsive aggression increases. Violent people are the result of a complex set of interactions between biological, psychological, and social factors. Biological markers, including resting heart rate and neurotransmitter levels, distinguish some violent persons from nonviolent persons.

Although a person’s genetic inheritance might lend a certain vulnerability toward violence, it is the interaction of that inheritance with the environment that results in a person who responds to the world in a violent fashion. Sometimes, violence may simply be a learned behavior, the only known and successful way the person solves problems. Some disorders are associated with violence, including epilepsy, nutritional deficiencies, brain tumors, and attention-deficit hyperactivity disorder (ADHD) and ADHD-related behaviors. Personality disorders and mental illness can go hand in hand with violence, as can substance abuse and head injury, childhood abuse, stress, sexual abuse, family dysfunction and breakdown, poverty, dementia, and exposure to toxic substances. Reactions to prescription drugs, use of anabolic steroids, and even fluid and electrolyte imbalances can lead to episodic rage and violence. Hormones can affect the expression of violence; a disproportionate amount of female aggression occurs around the time of menses.

Much of the media focus is on possible societal and cultural contributions to violence. Music, film, books, television, video games, and the Internet provide a wealth of suspects. The availability of guns, and in particular automatic assault weapons and high-capacity ammunition clips, also provides a focus point for blame. After all, Adam Lanza, the perpetrator of the Sandy Hook Elementary School murders, would have been significantly hamstrung were he armed with only a knife. Imaging has an emerging role in criminal cases, but it is worth noting that the law, too, grapples with trying to
identify what factors lead to violence. For example, victims and their families often file civil lawsuits seeking to hold video game manufacturers or filmmakers legally responsible for inspiring and causing specific people to act violently (see Box 3).

A current and particularly popular focus of blame is bullying or “peer aggression.” Harris and Klebald, the Columbine shooters, reportedly were subjected to “unfettered bullying”—both physical and verbal—at the hands of high school athletes. When the pair began their rampage, they shouted, “All the jocks stand up!” One author has tellingly observed that athletes receive consistent special privileges and notes that petitions for reinstatement for athletes caught with alcohol are common, while it is nearly impossible to imagine that the same fervor would be expended for a less popular kid who was caught with alcohol and suspended from school. It is apparently common for the 2 roles of bully and bullied to fuse, and what society tends to see as an inability to cope on the part of the bullied individual is really a series of signals of emotional distress. This individual’s overreaction is a signal of social incompetence, not psychological trouble.

Imaging’s Inroads

Mankind has long sought to study differences between violent and nonviolent brains. In the 19th century, the “science” of phrenology, or “head reading,” peaked in popularity. In phrenology, bumps on the outside of the skull, head shape, and other physical attributes are assigned values, including a tendency toward violence and crime. Immense strides have been made since then. Today, imaging makes exciting contributions to the study of the genesis of violence and helps us discern myth from reality in terms of factors that might contribute to the creation of a violent person.

When scientists seek to understand what biological differences might be common among aggressive individuals, methods for addressing the matter include peripheral and electrocortical psychophysiology and structural and functional neuroimaging. Cognitive neuroscience can make certain inroads in terms of understanding violence; PET and other neuroimaging methods expand on those insights by looking at brain activation during states of anger or comparing reactivity of test subjects to depictions of violence. It is next to impossible to image the brain of a person actually engaged in a violent act; however, through the use of medical imaging, researchers are able to construct experimental situations that permit them to study anatomical differences in brain structure as well as differences in brain connectivity and activation patterns. For example, experimenters can induce anger states through imagery manipulation and “imaginal processing” of scenarios in which subjects express unrestrained aggressive behavior. Such reaction patterns are compared to reactivity shown during a neutral scenario.

Box 3

**The Law Grapples With Causation: Attributing Fault in Sample Civil Cases**

**Wilson v Midway Games Inc**

Yancy, 13-year-old Noah Wilson’s friend, stabbed Noah in the chest, killing him. Noah’s mother, Andrea Wilson, sued Midway Games, asserting that Yancy was addicted to the company’s video game *Mortal Combat* and that Yancy believed he was a character in the video game, which led him to stab his friend. She attempted to hold the game manufacturer liable for her son’s death, arguing that Midway Games specifically targeted young audiences and designed the game to addict young players “to the exhilaration of violence.” The court dismissed her case.

**Byers v Edmondson**

Patsy Byers was shot by Sarah Edmondson and Benjamin Darrus during an armed robbery of a convenience store in Ponchatoula, Louisiana. Byers was left a paraplegic. The shooters repeatedly viewed the film *Natural Born Killers* and decided to mimic characters Mickey and Mallory by going on a crime spree in which they killed a Mississippi cotton gin owner and attempted to kill Byers. Byers sued several Hollywood defendants under various theories of liability, including that they failed to warn viewers of the potential negative effects of repeated viewing of the film, that they knew their film would incite people to violence, and that the film glorified violence. The court found that the mere foreseeability that a publication of some kind might be misused for criminal purposes is not sufficient to hold a creator or distributor liable.
Prior to the advent of today’s imaging techniques and as early as the 1940s, electroencephalography (EEG) revealed that psychopaths have greater than normal EEG signals in the frontal lobe during both waking and sleeping.19 Now, particularly intriguing research employing MR scanning is being conducted by Professor Kent Kiehl, principal investigator at the Mind Research Network in Albuquerque, New Mexico.20 In 2007, Kiehl had a portable MR scanner built to his specifications by Siemens installed at the Western New Mexico Correctional Facility. There, he scans inmates—psychopaths in particular. Although some inmates are too muscular to fit within the gantry, Kiehl reports a volunteer rate in excess of 90% among inmates at the facility. His cutting-edge findings provide a particularly strong example of the powerful tool imaging has become.

The science underlying antisocial behavior has come into its own, with researchers refining theories as to the numerous biological, environmental, psychological, and social factors that potentially contribute to human aggression.21 Medical imaging could be the most powerful tool at researchers’ disposal when it comes to exploring theories and reaching solid conclusions. An increased understanding of human violence will lead to better prevention, more appropriate legal responses to criminality, and improved treatment outcomes.

Causation: The Experts Weigh In Genetics

Among the factors implicated in aggression is that of a genetic predisposition toward violence. Some experts estimate that as much as 50% of the variance in adult antisocial behavior is heritable.22 For example, cognitive ability, which is partly determined by genes and the degree of cognitive ability demonstrated in middle childhood, has been differentially linked to aggression.23 Similarly, schizophrenia, a highly heritable mental disorder, is linked to an increased risk of aggressive behavior, including homicide.24,25 Borderline personality disorder, a commonly diagnosed mental disorder associated with violence against self and others, is another example of genetic influences on human aggression.26,27

Molecular biologists approach the phenomenon of human violence by analyzing DNA, searching for biological markers for violence, including a specific marker for psychopathy.28 Two genes already associated with alcoholism might be linked to psychopathy, and genetic variations associated with impulsive, violent behavior also are seen in psychopathy.29,30 Studies of twins have the advantage of comparing both genetic inheritance and shared or nonshared environmental influences and can be promising in terms of determining what might be inherited as opposed to environmental factors (ie, nature vs nurture).31 Since the late 1990s, twin studies consistently have revealed a genetic predisposition for antisocial and criminal behavior.32

Experts theorize that the wide number of genetic variants seen in humans has the potential to alter the structure and functioning of brain circuitry, hormonal systems, and the body’s stress response. Studies have identified monoamine oxidase type A (MAO-A), a risk genotype connected to a hyper-responsiveness of the brain’s threat-detection circuitry. A person with this risk genotype could be prone to violent responses in the absence of countervailing environmental influences such as a supportive parent.33

Genetic studies demonstrate that childhood physical aggression is highly heritable.34 Because aggressive behavior in children is a well-recognized major risk factor for developmental maladjustment of both child perpetrators and child victims, research scientists have explored possible genetic contributions to tendencies toward both social and physical aggression.35 Social aggression includes both nonverbal aggressive behavior (making faces, ostracizing another) and social manipulation of peer relations to harm another. The expression of physical aggression tends to diminish from early childhood, while social aggression increases with age, perhaps because most children learn that physical aggression is less socially acceptable and often leads to punishment. Social scientists have observed that even young children have the ability to use complex manipulative strategies, along with physical aggression, to harm their peers. So where does this aggression come from? Study authors ultimately concluded that in comparison with physical aggression, social aggression is determined less by genetic factors than by environmental factors such as parental and peer behaviors.36

Adding genetic information to brain-imaging data, a technique referred to as *imaging genomics*, permits researchers to study the brain function of individuals who possess a particular genetic phenotype.37 Clinicians
commonly encounter 2 children exposed to similar patterns of early adversity, such as child abuse, but who have different outcomes. Genes not only can create a predisposition or vulnerability toward aggression, but they also can protect against environmental influences or make a person more resilient than another in the face of adverse childhood experiences; imaging genomics allows experts to explore and perhaps explain these differences.16

**Neurodevelopmental Factors and Environmental Stressors**

Neurodevelopment, the development of the nervous system including the brain, begins at an early prenatal stage and continues through early adulthood.11 The cavum septum pellucidum (CSP) is a cavity within the brain that contains cerebrospinal fluid; it is part of the septum and of the brain’s limbic system, which are involved in the regulation of aggression.15 The CSP, a marker for fetal neural maldevelopment, forms or opens during approximately the 12th week of gestation and then begins to close during the 20th week of gestation. Closure of the CSP generally ends shortly after birth, from age 3 to 6 months, although there are individual differences in the degree to which the CSP fuses. Fusion or closure of the CSP is associated with rapid development of the hippocampus and amygdala, among other brain structures. Given its role in the limbic system, it also is associated with processing of emotions and emotional behavior.15

In some instances, the CSP fails to fuse and remains open into adulthood. To study the possible ramifications of a failure of the CSP to fuse and any connections between the CSP and various mental disorders, including antisocial personality disorder and psychopathy, experts have used medical imaging.16 In 2010, experts from several universities, including Professor Adrian Raine at the Department of Criminology, Psychiatry, and Psychology at the University of Pennsylvania, recruited test subjects from 5 temporary employment agencies. Subjects were diagnosed for antisocial personality disorder and psychopathy, and their criminal backgrounds were obtained through criminal history record searches provided by the Bureau of Criminal Statistics, Department of Justice. Structural MR imaging studies were conducted to obtain views of the CSP for each subject (see [Figure 1](#)).15

Among the study conclusions and findings were the following15:
- Subjects with an open CSP had significantly higher levels of psychopathy, criminal charges, and convictions when compared with subjects with a fused CSP.
- Even among those who lacked a diagnosis of antisocial personality disorder but who still demonstrated a criminal history, the CSP was larger than for subjects who had no mental disorder or criminal history.
- The study findings suggest the presence of this specific neurodevelopmental brain abnormality in antisocial persons and support the theory that early aberrations in the development of the limbic structures predispose individuals to antisocial behaviors.

There is some argument that the development of the CSP is largely a matter of genetic inheritance.16 Still, study authors encourage prenatal prevention of this condition, including reduction of smoking and alcohol use during pregnancy. For young children aged 3 to 5 years, they also emphasize the importance of better nutrition and the benefits of physical exercise on neuralgenesis, or the birth of new neurons.15

Recent research teaches that a child is born with nearly all the brain cells he or she will have and that the child’s interaction with his or her environment causes connections to form between brain cells.52 During adolescence and adulthood, the brain prunes these

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**Figure 1.** Magnetic resonance (MR) images showing the cavum septum pellucidum (CSP) highlighted in the blue boxes. A. Normal fused CSP in a nonantisocial test subject. B. Fluid-filled non-fused CSP in a test subject with antisocial personality disorder. Reprinted with permission from Raine A, Lee L, Yang Y, Colletti P. Neurodevelopmental marker for limbic maldevelopment in antisocial personality disorder and psychopathy. Br J Psychiatry. 2010;197(3):186-192. doi:10.1192/bjp.bp.110.078485.
connections, removing unused connections to create a more efficient brain.\(^\text{52,53}\) This is one way in which the environment—through experience—affects human development.

Stress, in whatever form it takes, may alter a person’s neurodevelopmental trajectory, cause an otherwise average child to engage in violence and become a violent adult. Physical, sexual, or verbal abuse, whether physically experienced or merely witnessed, can teach a child violence and even alter the normal course of brain development. Violent tendencies could result from head trauma as well as questionable and outright damaging parenting techniques and neglect. Prenatal exposure to alcohol and nicotine and childhood nutrition affect neurodevelopment and could be implicated as a contributing factor.\(^\text{55,56}\) Even birth order can alter a child’s trajectory. In a study that used MR imaging to study murderers with schizophrenia in comparison with nonviolent schizophrenics and murderers who did not have schizophrenia, murderers with schizophrenia were characterized by later birth order. Experts use imaging to study the precise ways in which these stressors are implicated in human aggression. Of particular salience to researchers is medical imaging’s ability to assist them in discriminating between brain anomalies that are neurodevelopmental in origin vs anomalies that might be the result of a violent lifestyle.\(^\text{56}\)

Abuse

Although the topic of abuse, or “developmental traumatology,” is much broader than is permitted exploration in this context, it is a problem that plays an enormous role in human development.\(^\text{57}\) Maltreatment can lead to changes in both brain function and structure in children.\(^\text{58}\) Abuse is a risk factor and actually can create a violent person.\(^\text{59}\) A child who witnesses domestic violence, a form of emotional abuse, is at increased risk for aggression and hostility.\(^\text{60}\) Children who suffer this type of early stress or adversity are at a greater risk for behavioral, social, and health problems that will affect them for the remainder of their lives.\(^\text{61}\)

Children could be injured by abusive adults or siblings, and often they witness adult partner violence or violence against their siblings. In both Canada and the United States, approximately 8% of children see violence at home each year.\(^\text{62}\) The problem of abuse is not unique to North America. One study reported that 12% of Finnish adolescents witnessed violence between their parents; 8% witnessed father-to-sibling violence, and 8% witnessed mother-to-sibling violence.\(^\text{63}\) Among 15- to 17-year-olds surveyed in Hong Kong, 7.5% witnessed adult partner violence, and 9.2% witnessed a parent assaulting a sibling. Witnessing violence between parents or violence by a parent toward a sibling creates a risk factor for being bullied at school, and seeing a brother or sister assaulted by a parent is associated with development of depression, anxiety, and anger in children.\(^\text{64}\)

Some experts theorize that domestic violence toward a mother affects her children’s well-being by altering her behavior. Often, the mother will become verbally aggressive toward her children.\(^\text{65}\) A parent who is abused reportedly also is less likely to be caring, warm, and supportively present for his or her children.\(^\text{66}\) When a parent is abused, children are more than 5 times more likely also to witness sibling physical abuse.\(^\text{67}\) Current research indicates that it is worse for a child to see a sibling abused than it is for the child to see a parent abused. This could be attributed to a form of survivor’s guilt or the creation of a stressful environment in which a child lives in a constant state of fear and uncertainty that he or she might be next in line for abuse.\(^\text{68}\)

Experts pose numerous theories to understand what purpose violent expression serves for children and adults who have been abused. Some victims experienced no nurturing attachment to another person and might have failed to develop empathy, a sense of others’ suffering. Survivors of abuse might have a lower threshold for emotional reactivity. They may express feelings only through violent channels in an attempt to regain control; they are emotionally volatile.\(^\text{22}\)

Research can provide insights into the effect of abuse on brain development. A team at McLean Hospital in Massachusetts identified 4 types of abnormalities resulting from abuse and neglect; they characterized the brain changes as permanent.\(^\text{69}\) Specifically, the experts noted:

- Persons with a history of abuse are 2 times as likely to have EEG abnormalities associated with self-destructive behavior and aggression.

- Functional MR studies and EEG coherence tests, which provide information about brain structure as well as function, show evidence of deficient,
arrested development of the left brain hemisphere in abused persons. The left hemisphere controls language, and the right hemisphere is responsible for visual-spatial ability, perception, and expression of negative affect. Abnormalities in the left hemisphere could explain development of depression and an increased risk of memory impairment often seen in abused persons.

- MR images revealed a smaller corpus callosum in abused children. The corpus callosum is one of the major information pathways between the right and left hemispheres of the brain. Functional MR imaging revealed that in abused persons, the degree of activity between the 2 brain hemispheres shifted more often than in persons who had not suffered abuse. Experts theorize that the diminished integration of the 2 hemispheres in abused people might result in dramatic personality changes or mood shifts in those who have been abused.

- T2 relaxometry, an MR technique that provides information about blood flow to the brain during a relaxed state, shows that the cerebellar vermis—a part of the brain involved in emotion, attention, and the regulation of the “emotional brain” or limbic system—is more active in persons who have been abused. This probable result of childhood trauma could impair the brain’s ability to maintain an emotional balance.

The brain’s long nerve fiber connections are created early in development, but the diameter and microstructure of nerve fibers continues to develop into adulthood. Postnatal factors, including stress from childhood abuse or neglect, have the potential to affect the development of nerve fiber tracts within the brain. Many researchers have used diffusion-tensor imaging (DTI), a type of MR imaging, to study neural connectivity and analyze white brain matter, which supports the network of connections between gray matter information processing centers. DTI allows clinicians to discern how water molecules are dispersed within the brain, providing a more detailed picture of nerve fiber tracts than is possible using conventional MR imaging. Results from one study suggest that adolescents who suffered childhood abuse have white matter changes that might lend an increased vulnerability to development of psychopathology, including depression and substance abuse.

Other researchers focus on the effect of merely witnessing domestic violence, excluding other types of child abuse. To learn what specific effect witnessing violence might have on brain development, researchers used DTI. Based on DTI findings, these experts concluded that exposure to early abuse targets brain regions and neural pathways that play key roles in regulation of emotions and in perception of adverse events. The implications for aggressive, violent behavior are clear: We regulate our emotions to stop ourselves from aggressing, and we rely upon the accurate perception of threats and events to prevent us from overreacting or acting in a way inappropriate to a given situation.

The experts believe the brain alterations they observed with DTI are evidence of the brain’s phenomenal ability to adapt, even to a situation as dreadful and fear-inducing as abuse. They are joined by others who theorize that observed neurodevelopmental brain anomalies resulting from child abuse are a form of adaptation and even protection. Study authors speculate that witnessing domestic violence could have caused overactivation of brain areas associated with processing fearful expressions and fearful voices. The developing brain was either damaged or compensated for the noxious stimuli by suppressing development of certain pathways. The resulting reduced connectivity might have had the beneficial effect of decreasing the child’s stress and the fear generated by hearing and seeing violence between the child’s parents. Unfortunately, there is a cost to this protective adaptation; these children often develop reduced visual processing speeds and are at an increased risk for dyslexia.

Other studies employing imaging to study the effects of child abuse have discovered additional alterations in the course of normal brain development. In one study, tensor-based morphometry, which permits comparison of brain volumes using MR images, revealed that the orbitofrontal cortex of the brain in physically abused children was small in comparison to nonabused test subjects. Volume alterations were actually present throughout the brain, but the frontal cortex was of particular interest because it is the brain region largely responsible for social and emotional regulation, including inhibition, appropriate response
to others’ moods, and self-regulation. All of these behaviors are pivotal to the expression or repression of anger, hostility, and aggression.  

EEG, MR imaging, computed tomography (CT), and neuropsychological testing proved helpful to experts investigating possible brain abnormalities in 31 people awaiting trial or sentencing for murder or who were appealing a criminal sentence. Abnormalities were found in nearly all people tested, and nearly all test subjects exhibited paranoid ideas and a misapprehension of social situations. Investigators reported a documented history of “profound, protracted physical abuse” in more than 80% of the subjects, and sexual abuse in more than 30% of subjects. The study authors concluded that “[i]t is likely that prolonged, severe physical abuse, paranoia, and neurologic brain dysfunction interact to form the matrix of violent behavior.”

Even so, some people who have been abused become violent aggressors while others are indistinguishable from nonoffending members of society. It likely matters when exposure to abuse began and how long it continued. Protective genes might work their magic, or certain genes might influence the production of neurotransmitters and render some children more vulnerable to the negative effect of certain environmental stressors. Apparently, it also matters what developmental stage the brain is in when exposed to an abusive situation. Brain regions differ in levels of reactivity to abuse, and for some brain regions, there are sensitive periods depending upon the stage of development. Some experts refer to “regionally specific windows of vulnerability in brain development” and note that, for example, gray matter volume in the frontal cortex is most affected by abuse that occurs at 14 to 16 years of age (see Figure 2). The hippocampus is most affected at ages 3 to 5 (see Table), and the corpus callosum is most affected at ages 9 to 10.  

One of the primary ways in which experts believe parenting could contribute to the creation of a violent person is by pathologies of attachment. Attachment refers to a behavioral system that ensures survival of an infant by maintaining a close bond between the infant and an adult caretaker. One aspect of attachment is anxiety on the part of the infant. This anxiety serves an important evolutionary purpose. An infant becomes anxious in the presence of a stranger, when the parent leaves the room, and when the child anticipates loss. The baby’s cries help to keep the caretaking parent close to the child and ensure the child’s safety from predators. Experts theorize that when attachment fails, a child might grow to suffer from a chronic emotional detachment from others, a trait common in violent psychopaths. Attachment might fail as a result of childhood abuse, but it also can fail because a parent is nonresponsive and withdrawn. A Danish study showed that adult males with a history of maternal rejection during the first year of life and whose mothers experienced birth complications had a predisposition to patterns of violent criminal behavior.

Social aggression in particular might be the result of modeling by a parent and mimicry on the part of the child; if a parent uses manipulation in the form of withdrawal of love or injection of shame and guilt, then a child is likely to repeat that behavior in the form of social exclusion of peers and threats of withdrawal of friendship. When a parent uses psychological control measures to interact with the other parent, children are watching and might be influenced by their observations. Because each child experiences parental behavior in a way unique to the child, consequences of these types of parenting techniques are not always 100% predictable. Nevertheless, a growing body of evidence indicates that negative parenting behaviors create fertile soil in which an aggressive child might grow.  

Parenting

The association between violent aggression and parenting style is well recognized. Both physical and social aggression in children can be the product of parenting behaviors, including coercion, physical punishment, and a lack of responsiveness. We do what we have learned, and our most influential teachers are our parents.

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The shooter perceives himself or herself as marginalized.

The shooter suffers from psychosocial problems that magnify this sense of marginalization.

The shooter believes that the attack will resolve dilemmas (cultural scripts such as films create models for problem solving).

Systems designed to identify troubled teens fail.

Guns are readily available.

Aggression begets aggression, and the tendencies of aggressive children are further fostered by their affiliation with hostile peers. These types of friendships or associations also play a role in the development of socially aggressive behavioral strategies. Even among preschoolers, a 3-month-long interaction with aggressive peers has been associated with an increase in aggression toward teachers. Experts believe that these peer interactions reinforce existing aggressive tendencies and modeling of aggressive behaviors.

Can imaging illuminate any ill effects resulting from peer verbal abuse and bullying? Experts used DTI to examine what might be the long-term effects of childhood exposure to peer verbal abuse on white matter tracts. Study authors first noted that victims of peer aggression, including physical and verbal aggression, are more likely to carry weapons to school and to engage in fights; they also are reportedly more likely to hurt nonhuman animals.

Through interviewing a community sample of subjects ranging in age from late teens to early adulthood, the study authors noted a 3- to 4-fold increase in “limbic irritability” or emotional volatility in those who had been exposed to peer verbal abuse. This particular form of abuse apparently peaked in middle school, a finding that supported previous observations that peer physical aggression declines between 8 and 18 years of age while verbal abuse increases between ages 8 and 11, plateaus, and then declines with greater maturity, between ages 15 and 18.

DTI results showed a relationship between the degree of exposure to peer verbal abuse and alterations in several areas of the brain, with the most robust alterations being in the corpus callosum, one of the major information pathways between the right and left hemispheres of the brain. Study authors suspect—not coincidentally—that the most sensitive developmental period for this portion of the brain is during middle school.
years or the peripubertal period. They also acknowledge that the observed brain alterations might have preceded abuse, creating an “odd” individual who was then targeted by peers. In summary, however, study authors believed that their imaging findings should increase concerns that “exposure to ridicule, disdain and humiliation, from parents, partners or peers, is emotionally toxic and may adversely impact trajectories of brain development.”

**A Culture of Violence?**

In Kentucky in 1997, Kelly Carneal accompanied her brother, Michael, a freshman, to school. He took a bundle from the car and identified it as his English project. His sister described what happened when the siblings reached the high school lobby:

> I heard what sounded like firecrackers….They make the little popping sound….And then I saw people turn and start to run. It was like a flower: There was a group of people and it just kind of folded away….And my brother was standing there. He had the gun in his hands… and was looking straight ahead. His face looked different, and his body posture was different….He looked like a completely different person. I would not have recognized him had he not had on the same clothes as he had on that morning. I started to walk towards him, and he turned his head and he looked at me. And I realized he didn’t know who I was. I thought, “My brother is going to shoot me!” So I turned around and ran.”

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**Table**

<table>
<thead>
<tr>
<th>Brain Regions</th>
<th>Associated Activity</th>
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<tbody>
<tr>
<td>Prefrontal cortex (PFC) – composed of the anterior cingulate cortex, medial orbitofrontal cortex, medial PFC, ventromedial PFC, and dorsolateral PFC</td>
<td>The PFC manages 3 cognitive abilities important to controlling violent impulses: the ability to hold relevant information and goals in mind to plan and determine the relative value of available options, the ability not to act on desires or impulses as a means of achieving a future goal, and switching or flexibly updating goals and relevant information. This region is associated with empathy, reasoning and decision-making, impulse control, conflict monitoring, regret, and ethics. The anterior cingulate cortex is associated with the integration of current information with learned information and the ability to detect conflicts and correct commission errors.</td>
</tr>
<tr>
<td>Parahippocampal cortex, amygdala, and hippocampus</td>
<td>These regions detect threats and anticipate pain. Frequently implicated in psychopathy, this area is associated with aggression, impulsivity, irresponsibility, emotional processing, and regulation (including fearful expression processing and thus empathy), guilt, remorse, and moral reasoning.</td>
</tr>
<tr>
<td>Limbic region</td>
<td>This area, which processes emotions and emotional behavior, is key to psychopathology.</td>
</tr>
<tr>
<td>Caudate nucleus – sits astride the thalamus, which sits atop the brainstem between the cerebral cortex and midbrain</td>
<td>This region is associated with learning and memory; the thalamus receives and relays sensory information to the cerebral cortex.</td>
</tr>
<tr>
<td>Temporal lobe, including the medial temporal lobe</td>
<td>Language comprehension, long-term memory, and processing of auditory and visual input take place in this region. A malfunction in this area might lead to misunderstanding of a social setting, misapprehension of social cues, and misinterpretation.</td>
</tr>
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</table>

*Although these selected brain regions are associated with specific human behavior traits, it is important to remember that another factor implicated in behavior is the ability—or impaired ability—of these regions to communicate and interact with one another.*
Three children died; 5 were wounded. Michael Carneal’s profile fits within FBI statistics and the growing body of research conducted by social scientists who study youth violence: he was a white male in a rural setting (a larger proportion of mass murders take place in small towns and rural areas), and he first manifested violent tendencies between 14 and 18 years of age. An FBI review of 18 school shootings concluded that potential warning signs of a school shooter include turbulent parent-child relationships, family acceptance of pathological behavior, access to weapons in the home, and lack of limits or monitoring of television viewing and Internet use. Identifying a potential shooter based upon this profile or any other similar statistical compilation is impossible, however, because so many nonviolent children fit within these parameters.

We live in a society in which violence is expressed in music, films, books, television, and games. Depictions of violence are nothing new; Homer’s *Iliad* includes graphic descriptions of the Trojan war. Blood spurts, people are hacked apart with swords, and warriors bludgeon each other with stones. The Internet offers information about how to build explosive devices and guns. Even old-fashioned books include how-to information, along with informative reports and studies of rampage shooters and serial killers. The dissemination of this type of information, although important to our examination of these issues, can inspire people who seek to wreak havoc on the lives of others. If American society is to take a multifaceted approach to reducing criminal violence and sensational school shootings, it makes sense to learn to what degree, if any, mass media might have influenced shooters like Michael Carneal and others.

Available scientific evidence concerning the effect violent media might have on youth is suggestive but inconclusive. Because physical aggression in childhood is one of the greatest risk factors for later violent behavior, it is important that we increase our understanding of what factors could increase or decrease youth violence. Possible influential aspects of media violence in children are desensitization to consequences of violence, the promotion of violence as a solution to problems, desensitization to pain, and the effect of pain on others.

Exposure to media violence is associated with a variety of antisocial behaviors, from violence against toys to interpersonal criminal violence. But does exposure lead to violence, or are youths who are enamored of violent video games and film already prone to violence and so select this type of entertainment and stimulation? Clearly, only a small fraction of children exposed to media violence become violent.

Interactive video or Internet games are a part of daily life for American children, who in the 1980s played an average of 4 hours per week but who now play an average of 13 hours per week. Boys tend to play more games than do girls, and they tend to choose more violent games. Some studies indicate that the more time spent playing video games, the greater the rate of aggression and the poorer school performance. At the same time, playing educational games could be related to positive outcomes, particularly in terms of attention span and educational performance. Gender does not appear to mediate the negative effects of video gaming, but parental monitoring is associated with better school performance, fewer behavior problems, less violent game play, and more educational game play.

Of particular concern to many experts in child development are first-person shooter games that include “a human perpetrator engaging in repeated acts of justified violence involving weapons that results in bloodshed to the victim.” As these games have become more sophisticated and realistic, concerns have grown, and some studies have shown that active participation in a video game leads to more short-term aggressive behavior than does passively watching the same video. Other study results conflict, concluding that violent video game playing does not lead to more aggressive expression or desensitization to violence. Further confusing the picture is the observation that children who already display aggressive tendencies tend to choose and play more violent video games.

Recently, a German study of volunteers between the ages of 18 and 26 years used functional MR (fMR) imaging in an attempt to shed more light on this complicated issue. While undergoing fMR scanning, test subjects played *Tactical Ops: Assault on Terror*, a violent video game in which players either kill opponents or are killed. The video display and accompanying audio track were recorded for content analysis and
synchronization with fMR imaging data. Both before and after entering the scanner, subjects were asked to complete a mood scale containing adjectives describing positive and negative emotions. The scale was used to measure emotion before and after playing the video game.

Results showed relative deactivation of the caudate nucleus and portions of the prefrontal cortex (the medial orbitofrontal cortex) when subjects failed in the game. These portions of the brain are associated with memory and learning, and in this specific game context, with reward-prediction error assessment and learning. Researchers found no indication that violent events were directly rewarding to test subjects.

The German study test subjects were not young children but were at the later end of adolescence. Some studies have concluded that the long-term effect of televised violence is greater for children than for adolescents, and so age could matter in terms of the effects of video games. Content also might be a determining factor, explaining why some studies find a deleterious impact associated with violent media while other studies find little to no harmful effects. Some evidence flowing from television research indicates that a focus on the pain and suffering of the victims of violence actually can have a socially approved effect in that it reduces any harmful effect from depicted violence. Glamorizing an attractive, violent perpetrator, on the other hand, might tend to increase harmful impact.

It only makes sense that if children are exposed to a great deal of emotionless violence, if they see violence glorified and touted as the superior problem-solving technique, then they will copy that behavior; they will emulate the violent perpetrator. Psychologists refer to cognitive scripts, which are our individualized ideas about what might come to pass in our environments and how we might appropriately respond to such events. We develop these scripts over a long period of time beginning in early childhood, through observation and reinforced learning. Reportedly, once formed they are challenging to change. Some experts assert that if a child is rewarded for acting aggressively in the context of a video game, over time the child’s script becomes one in which the world is a violent place where aggression is the best response.

Common sense may lend us the best advice. Children learn and behave in a way that conforms with the behaviors they have seen modeled, so focus on improving parental knowledge and parenting techniques, and on improving the culturally impoverished home lives of so many children, is crucial. Imaging could provide clues to this multifaceted puzzle and give us solid information with which to parent children and make decisions.

Neurotransmitters and Hormones

Various neurotransmitter and hormonal systems appear to modulate aggressive behavior. Neurons communicate with one another by means of chemicals known as neurotransmitters. These chemicals carry messages from one neuron to another across a synapse, or gap, between them. Scientists speculate that abnormal neurotransmitter levels, and in particular low serotonin levels, influence the expression of violence.

Hormones, too, have been implicated in violence, and a key role is likely played by testosterone, a hormone associated with domination behavior. Cortisol, a hormone excreted when we are under stress and the hormone largely responsible for triggering the fight-or-flight response, provides another example of the effect hormones might have on violence. Some studies have found that naturally occurring increases in cortisol levels from morning to afternoon might be linked to physical and social aggression in children aged 3 to 8 years.

Testosterone has long been characterized as the “hormone of aggression,” but it can only change the likelihood of behavior; it does not, in and of itself, create aggression. Highly successful athletes and businessmen tend to have high levels of testosterone but are not necessarily more prone to violence, so the hormone does not independently promote aggression. Although women’s testosterone levels are approximately 10 times lower than men’s levels, the hormone still affects aggression in women. In a study conducted on female inmates, women’s level of aggressive dominant behavior in the prison setting was strongly correlated with their testosterone levels.

An Australian study used fMR imaging to observe how brain activation patterns might be altered by different levels of cortisol and testosterone. Healthy male participants were insulted and asked to control their
anger while being scanned. Current theory proposes that natural testosterone concentrations have the greatest effect on male violence when cortisol levels are low, and MR imaging revealed different recruitment of brain networks depending upon hormone levels. Researchers concluded that their experiment showed a possible neural mechanism through which testosterone and cortisol might influence anger control.¹⁴

A long-held tenet of the biology of violence is that individual differences in serotonin synthesis provide at least a partial explanation of violent behavior. Serotonin is associated with feelings of happiness and well-being, and the theory has been that low levels of serotonin may contribute to displays of physical aggression.⁴⁹ Rates of serotonin metabolism likely are affected by genetic and environmental influences. A recent Canadian study compared men with histories of high levels of physical aggression in childhood but desisting during adolescence to men who had low or normal patterns of aggression throughout childhood and adolescence.⁴⁹ The researchers used PET in conjunction with injection of a synthetic analog of serotonin's precursor, tryptophan, to estimate brain synthesis of serotonin and to determine what differences might exist between the 2 groups of test subjects.

Test results showed that the men with childhood histories of violent behavior had markedly lower levels of serotonin synthesis in the orbitofrontal cortex, a scenario typically associated with patients diagnosed with impulse control disorders (see Figure 3).⁴⁹ What is puzzling about this finding and what calls into question traditional thinking about serotonin metabolism and violence is the fact that this group of men—despite their dramatically different brain metabolism of serotonin—no longer engaged in violent behavior. If the longstanding theory held true, men with low levels of serotonin synthesis should be prone to angry displays and violence, but these men were no longer exhibiting those types of behavior.

Study authors suggest that low brain serotonin levels in the formerly aggressive group of men might act as a “vulnerability” trait for violence, but other protective environmental factors, including brain maturation and learning, may have exerted a sufficient influence during adolescence and adulthood to support impulse control. The study actually provides significant hope:

In this instance, at least, environment, learning, and maturation might well trump a biological predisposition toward violence.

Another recent experiment used fMR imaging to study the role of serotonin in reactive aggression, or aggression that occurs after interpersonal provocation (as opposed to impulsive aggression).⁷⁵ After testing subjects’ tolerance for thermal stimulation (ie, artificially induced pain), researchers artificially lowered serotonin levels by means of acute tryptophan depletion; male test subjects consumed a drink that either contained tryptophan or lacked tryptophan. Five hours after the drink had been administered, when the effects of tryptophan depletion were known to be greatest, subjects were scanned. Using some counterfeit participants to interact with test subjects, researchers informed subjects that in the game they were playing an opponent could punish losers by application of heat to the back of their left hands. Scans revealed the brain’s processing of this provocation and the effect of serotonin levels on reaction to provocation (see Figure 4). Test results detected only subtle effects attributable to lowered serotonin levels. As with the Australian study discussed above, this result brings into question long-held theories about the relationship between serotonin levels and aggressive behavior.⁷⁵

![Figure 3. After mathematical computation, the composite PET image represents a statistical comparison between test subjects with a history of high physical aggression during elementary school compared with subjects who did not have a history of physical aggression. The color-coded portion of the images shows a marked decrease in brain serotonin synthesis capacity on both sides of the orbitofrontal cortex in subjects with a history of physical violence. Reprinted with permission from Booij L, Tremblay RE, Leyton M, et al. Brain serotonin synthesis in adult males characterized by physical aggression during childhood: a 21-year longitudinal study. PLoS ONE. 2010;5(6):e11255. doi:10.1371/journal.pone.0011255.](image-url)
**The Bottom Line**

Violence is a complicated human behavior resulting from the interplay of numerous factors and not attributable to any single parenting failure, gene, inadequate schoolteacher, playground bully, hatred-infused game, song or film, or chemical anomaly. Still, as humans we have the capacity to exercise choice; we are not wholly at the mercy of factors beyond our control. Experts continue to tease out the threads that combine to form aggression, and with the help of imaging they are able to reexamine and either prove or disprove long-held theories about why one person might aggress against another and why some people seem prone to live a life of unimaginable violence and unremitting anger.

**Imaging, Violence, and the Courtroom**

Those who perform in courtrooms are just beginning to contemplate the power of neuroscientific evidence. Yet, as one author noted:

> While there is no denying that brain imaging is a powerful tool, whether used for medical or legal purposes, it is also clear that, like any tool, brain imaging can be used for good or for ill, skillfully or sloppily, and in ways useful or irrelevant.\(^7\)

Judges and lawyers are not scientists, and medical practitioners are not legal scholars; the tensions between the disciplines become abundantly clear in the legal setting, where attorneys might seek to use medical information in ways that medical professionals consider misguided and inappropriate. In discussing a physician’s role in preventing violence with respect to patients who seek help for episodic attacks of rage that are often accompanied by physical violence (intermittent explosive disorder), some from the medical side have noted: “Considering a violent perpetrator to be responsible for their actions may be a critical legal policy to uphold, but such a policy may impede diagnosis.”\(^7\)

Despite these tensions, attorneys are beginning to use imaging to prosecute and defend people accused of violent crimes. Medical imaging makes its appearance at nearly all stages of the legal process, from early determinations as to a defendant’s competence to stand trial to guilt determination, insanity defenses, sentencing and parole, and appeal. Radiologic studies could assist courts in determining whether imposition of a death sentence is appropriate, predicting a defendant’s propensity for future aggression and recidivism, and gauging an inmate’s threat to security or vulnerability to violence within the prison setting. Did a defendant willingly and intelligently waive his or her Miranda rights? Is he or she malingering, or does he or she have a genuine mental disorder? Neuropsychologists, among others, are being asked to testify regarding these issues and to use imaging evidence to illustrate and bolster their testimony.\(^7\)

Recognizing the importance of these issues, the John D and Catherine T MacArthur Foundation created the Law and Neuroscience Project and the Research Network on Law and Neuroscience, both of which are headquartered at Vanderbilt University Law School in Tennessee.\(^\text{19}\) The organizations foster interdisciplinary research among more than 50 scientists, law professors, and judges throughout the country. Although medical professionals might be leery of courts’ use of medical information for what appear to be incongruous legal reasons, imaging is in the courtroom to stay. In some instances convicted defendants have alleged that their trial counsel was ineffective for failing to obtain and present medical imaging evidence.\(^7\)

**Practical and Potential Applications of Imaging**

Benjamin Cole’s 9-month-old daughter was crying, and Cole could not get the child to stop.\(^7\) She was lying on her stomach, and he grabbed her by the ankles and pushed her legs toward her head, stretching the aorta.

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**Figure 4. Functional MR images of the brain.**

A. The effect of provocation, with an increased brain response in an anterior portion of the prefrontal cortex, which is associated with the integration of current information with learned information and the ability to detect conflicts and correct commission errors. B. The brain’s reaction to provocation after consumption of a drink containing tryptophan, a precursor to serotonin. Reprinted with permission from Krämer UM, Riba J, Richter S, Münte TF. An fMRI study on the role of serotonin in reactive aggression. PLoS ONE. 2011;6(11):e27668. doi:10.1371/journal.pone.0027668.
He continued pushing her legs toward her head until she flipped from her stomach onto her back. Cole’s handling of his daughter caused her spine to snap in half and her aorta to be torn completely through. Having successfully silenced his daughter, Cole played video games until his wife questioned him; he denied knowing anything was wrong with the child. Only after the ambulance arrived did Cole attempt CPR. The child died. The medical examiner testified that the child’s injuries were not the result of normal back-bending by such a young child but were instead the result of application of a great amount of force. Eventually, Cole confessed to police.

Cole was tried by an Oklahoma jury and convicted of first-degree child abuse murder. He was sentenced to death but later challenged his conviction by filing a petition for a writ of habeas corpus and claiming, among other things, that he was not competent to stand trial, that he suffered from paranoid schizophrenia with grand delusions and so was unable to assist his counsel. Furthermore, Cole claimed he was deprived of a fair trial when the judge denied his counsel’s request for a delay in the trial so counsel could hire an expert who was able to testify about alleged abnormalities in an MR imaging scan of Cole’s brain. Cole’s attorney had informed the court of staff shortages in the public defender’s office and explained difficulties he had encountered in scheduling the MR scan.

In support of the petition for writ of habeas corpus, Cole submitted an affidavit from a neuropsychologist who had reviewed the MR images and who indicated that “individuals like Mr. Cole who suffer from this amount and type of damage are more likely to act violently”; the expert opined that the brain damage seen on the scans likely existed at the time Cole killed his daughter.” Cole’s defense counsel wanted to place the medical imaging evidence before a jury in a new trial for the purpose of explaining how brain damage could have been at least partially responsible for Cole’s actions—that Cole’s behavior was beyond his control. Yet, other experts who reviewed the MR scans indicated that the brain lesion seen on the scans was nonspecific and “might be seen in multiple sclerosis, tumor, or small abscess.” Thus, there was a difference of opinion between experts as to the nature of what the scans revealed and the effect, if any, of abnormalities visible in the scans. Ultimately, the court denied Cole’s petition for a writ of habeas corpus, and Cole remains on death row awaiting execution.9

The law views insanity as a defense that precludes guilt, with the policy underlying this legal theory being that society does not wish to punish those who do not know what they are doing and cannot control their behavior. The insanity defense, however, rarely is successful.19 Medical imaging evidence, which presents an actual picture of a person’s brain anomalies and can allow judges and jurors to see a defendant’s physical impairments, might change the effectiveness of this defense. Some have argued persuasively that the law needs to adjust, to recognize a continuum of guilt, a sliding scale of those who are able to recognize right from wrong and control their behaviors.19 Because science has advanced since the insanity defense was first recognized by the law, some argue the law should catch up and bring itself into line with current scientific evidence that indicates, for example, that damage to the PFC undeniably causes aggression and acquired psychopathy in some individuals.18,19

In 1992, Herbert Weinstein strangled his wife and threw her out of their apartment window in an effort to make her death look like a suicide.19 Weinstein argued that an arachnoid cyst apparent on a PET scan of his brain proved that his ability to reason had been impaired. Arachnoid cysts are cerebrospinal fluid–filled sacs located between the brain or spinal cord and the arachnoid membrane, 1 of the 3 membranes that cover the brain and spinal cord. They can be present at birth or might develop as a result of head injury, meningi-tis, or tumors or as a complication of brain surgery.19–80 Weinstein eventually gave up the defense and pled guilty, but admission of the PET evidence drew attention from both legal and medical communities.19

Grady Nelson sexually assaulted his wife’s 2 daughters.7 He also had been convicted of raping a 7-year-old neighbor. When Nelson added to his list of criminal convictions by stabbing his wife 61 times, his defense introduced testimony from an expert in quantitative EEG brain mapping to show brain injury and argue that Nelson should be spared from the death penalty. The defense expert testified that the brain injury was responsible for Nelson’s violent impulses. At least one juror found the testimony and supportive neuroimages persuasive, and Nelson was sentenced to life imprisonment rather than death. In retrospect, we can examine whether this type of imaging evidence was admitted appropriately. Because they gave jurors a purported picture of Nelson’s brain
anomaly, the images might have been overly persuasive or simply a current, viable tool for assisting a jury in its efforts to mete out justice.

Frontotemporal dementia is a progressive neurodegenerative disorder with an age onset in the late 50s, is shared equally by men and women, and likely the result of a genetic inheritance. Many symptoms accompany this form of dementia, including loss of empathy, disinhibition, compulsive acts, and transgression of social norms. People with this disorder can act in a criminal way knowing exactly what moral rules and conventions would have to say about such behaviors. They retain the capacity to distinguish right from wrong and so are not legally insane, and yet the disease renders them incapable of controlling their behaviors.

Persons with ADHD are more likely than people without ADHD to engage in episodic aggression or antisocial conduct. Some people with epilepsy display aggressive, assaultive behavior. Questions about whether these people are responsible for their actions and whether the law should hold these individuals responsible are up for debate. Some kind of exception for brain-injured persons who are not insane but who, no matter their preexisting personalities or impeccable records of good citizenship, can no longer quell violent tendencies might be the answer. However, where should we draw the line in terms of punishing people who can, to some degree or another, control their behaviors?

Recent studies have found that expert neurological evidence is more persuasive than other varieties of expert and nonexpert evidence. If this form of evidence is so powerful and persuasive, courts should be particularly careful about when it is admitted and when it is kept out of the courtroom. Courts need to know where to draw the line, and judges, who are not schooled in radiology or neuroscience, will have to rely upon experts and attorneys’ legal arguments to provide them with the information they need to make necessary determinations about the reliability of evidence and whether proposed evidence is persuasive concerning issues genuinely before the court. Therefore, we should be concerned about placing medical imaging evidence before nonscientist jurors and judges.

A recent experiment attempted to dissect some of these issues by conducting 2 mock jury experiments online. Study authors sought to test the effectiveness of neuroimages on the penalty phase of death-sentence murder trials. Mock jurors were randomly assigned to fact patterns with a variety of contingencies, including the defendant’s diagnosis (psychopathy, schizophrenia, normal), type of expert evidence supporting that diagnosis (clinical observation, genetic factors, neurological testimony without images, neurological testimony with images), evidence of predicted dangerousness (high or low), and whether the side introducing the evidence was the prosecution (arguing for aggravation of murder charge) or the defense (arguing that the defendant’s diagnosis should result in mitigation—life imprisonment rather than death).

The results are both startling and sobering in terms of the effect of neuroimaging evidence and the caution courts should use in managing this type of evidence:

- For psychopaths, neuroimages reduced judgments of responsibility and death sentences.
- For schizophrenics, neuroimages increased judgments of responsibility, but nonimage-supported neurological evidence decreased death sentences, judgments of responsibility, and dangerousness.
- Overall, psychopaths were more likely to receive death sentences.
- When experts testified that a defendant was dangerous, death sentences increased.
- When the expert evidence was not supported by neuroimages (ie, it was clinical, genetic, or expert testimony alone), there was a backfire effect: jurors found contrary to whichever party was offering the evidence.
- When the expert evidence was supported by neuroimages, jurors were persuaded by whatever position the offering attorney was arguing.

Kiehl’s ongoing research at the Mind Research Network using MR imaging to study brain differences in incarcerated psychopaths has revealed that in psychopaths there is decreased neural activity in the paralimbic regions of the brain—the region of the brain that contains structures associated with moral reasoning, memory, and inhibition. Psychopaths capably remember emotional words as well as nonpsychopaths, but they take longer to recognize the emotional content of words. MR images obtained during experiments assessing abilities to engage in impulse control show that psychopaths are much less likely to inhibit their responses. This finding supports observed behaviors
characteristic of psychopaths, including a nomadic, impulsive lifestyle. Kiehl’s research, combined with that of others, demonstrates that psychopaths’ brains are “markedly deficient” in areas of the brain’s paralimbic region critical to moral judgment, including the ability to distinguish moral issues, inhibit responses pending resolution of a moral issue, and make a decision concerning a moral issue.13 Kiehl wisely notes that imaging could help to identify psychopaths during adolescence, thus permitting early interventions that might at least diminish the likelihood of a long, destructive criminal career.14 At the same time, imaging could come into play in terms of excusing psychopathic behavior; after all, if the psychopath’s brain malfunctions when it comes to impulse control and assessment of moral vs immoral behavior, can we legitimately hold him or her as culpable as we do people whose brains function normally? Some assert the law should take into account the psychopath’s faulty moral recognition.

Psychopaths are much more likely to commit crimes once released from prison than are nonpsychopaths; compared with a nonpsychopath convicted of an identical crime, the average psychopath is in and out of prison 3 times before the nonpsychopath recidivates.15 Psychopathy is also a strong predictor of sexual violence, and the FBI reports that psychopathic sex offenders are 2.43 times more likely to be released than are nonpsychopathic sexual offenders.16 Some experts believe that the psychopath’s acting ability lets him or her more easily manipulate members of parole boards despite a longer history of offenses and widely recognized, elevated risk of recidivism.17 Psychopaths are reportedly particularly skillful at imitating emotions that they are convinced will lessen their punishment.

Given these dangers, medical imaging could be used for what is being called neuroprediction, an effort to gauge the likelihood that a convicted person, once released, will harm someone else.18 Risk assessment tools based upon carefully gathered behavioral data are in use in the criminal justice system. Experts have just begun to debate whether brain scan data should be incorporated into assessments that attempt to predict future dangerousness.19 Kiehl and his associates have demonstrated that offenders with specific patterns of error-related brain activity seen during a test of impulse control were approximately 2 times more likely to be rearrested than offenders more capable of impulse control.20 Such fMR imaging results could be seen as a neurocognitive biomarker for “persistent antisocial behavior” and arguably be used by parole boards or others considering sentencing options and release dates for violent offenders.

If medical imaging is used to identify neurocognitive biomarkers that indicate a tendency toward violence, the law must consider how to respond if the brains of all or most violent criminals are different from those of law-abiding citizens. Researchers used EEG, MR imaging, CT, and neuropsychological testing to evaluate 31 prisoners awaiting trial, sentencing for murder, or who were appealing their convictions.21 Results showed widespread dysfunction and abnormalities in all test subjects, including:

- Frontal lobe dysfunction in 64.5%.
- Temporal lobe abnormalities in 29%.
- Disabilities, including borderline or full mental retardation and cerebral palsy.
- Mental disorders, including paranoid schizophrenia, dissociative disorder, and depression.
- EEG abnormalities.
- MR imaging and CT abnormalities consisting primarily of white matter changes and brain atrophy.

Obviously, there are no easy answers to the numerous challenges posed by the emergence and growing use of imaging evidence, and the law is slow to act. Participants in the MacArthur Foundation Law and Neuroscience Project have summarized some of the most pressing issues surrounding the possible uses of imaging evidence in the criminal justice system:

The ongoing challenge for neuroscientists and lawyers is to reliably distinguish legally excusable neural causes from inexcusable ones, and to present this information in an unbiased manner. Further, many brain functions, and certainly brain structure, change over time, so a test today may not necessarily tell us anything about acute brain function…at the time of the conduct at issue in a criminal case.22

Conclusion
Medical imaging presents exciting opportunities for understanding how violence begins, what we might do to prevent violence, and how we should treat violent offenders—both medically and within the criminal justice system. As the United States struggles to comprehend...
what seems to be an endless flow of senseless violence, we wonder how we might recognize violence before it happens and stop it in its tracks. Ultimately, imaging might provide answers, but in the meantime, experts who have studied rampage school shootings offer this advice:

*We take a hard look at the options for intervention and conclude that the best bet we have for prevention lies not in trying to identify the people who are going to shoot their teachers and classmates – though preventative mental health measures are good policy across the board – but rather on intercepting the flow of information when the threats fly. This is a challenge, given the fiercely private world of adolescents, but it is not an impossible task.*

The Unabomber’s brother turned him in, saying that he knew he had to stop his brother from killing again. Grant Acord, the Oregon teenager arrested in May 2013 before he could ignite his school with pipe bombs, Molotov cocktails, a drain cleaner bomb, and a napalm bomb, was taken into custody after someone tipped off police. Are we paying enough attention?

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**References**


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Imaging’s Insights Into Human Violence

1. Violence associated with patient care, including physical assaults, is reported to be the most prevalent cause of ______ in health care organizations.
   a. mortality
   b. nonfatal injury
   c. psychological disturbances
   d. ulcers

2. Which expression of violence is a response to an immediate threat and involves arousal of the autonomic nervous system?
   a. predatory attack
   b. affective defense
   c. instrumental violence
   d. social aggression

3. Predatory violence:
   1. is emotionless.
   2. lacks autonomic arousal.
   3. is premeditated and purposeful.
   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3

4. Some experts estimate that as much as ______ % of the variance in adult antisocial behavior is heritable.
   a. 12
   b. 28
   c. 34
   d. 50

Read the preceding Directed Reading and choose the answer that is most correct based on the article.
5. Which technique permits researchers to study the brain function of individuals who possess a particular genetic phenotype?
   a. diffusion-tensor imaging (DTI)
   b. T-2 relaxometry
   c. imaging genomics
   d. neuroprediction

6. ______ can lead to changes in both brain function and structure in children.
   a. Maltreatment
   b. Dyslexia
   c. Attachment
   d. Survivor’s guilt

7. Current research indicates that it is worse for a child to see a sibling abused than it is for the child to see a parent abused. This could be attributed to a form of:
   a. Stockholm syndrome.
   b. survivor’s guilt.
   c. attachment disorder.
   d. reactive aggression.

8. A research team at McLean Hospital in Massachusetts noted abnormalities resulting from abuse and neglect, including:
   1. electroencephalography (EEG) abnormalities.
   2. arrested development of the left brain hemisphere.
   3. a larger corpus callosum.

   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3

9. ______ allows clinicians to discern how water molecules are dispersed within the brain to provide a more detailed picture of nerve fiber tracts than is possible using more conventional imaging.
   a. Functional magnetic resonance (MR) imaging
   b. Positron emission tomography
   c. T-2 relaxometry
   d. DTI

10. ______ permits comparison of brain volumes using MR images.
    a. T-2 relaxometry
    b. DTI
    c. Tensor-based morphometry
    d. Single photon emission computed tomography

11. A malfunction in the ______ might lead to misunderstanding of a social setting and misapprehension of social cues.
    a. brain stem
    b. prefrontal cortex
    c. temporal lobe
    d. caudate nucleus

12. Which hormone is associated with domination behavior?
    a. estrogen
    b. cortisol
    c. tryptophan
    d. testosterone

13. ______ is a hormone excreted when we are under stress and is largely responsible for triggering the fight-or-flight response.
    a. Estrogen
    b. Cortisol
    c. Insulin
    d. Testosterone

continued on next page
14. Attorneys are beginning to use medical imaging in the legal process, including for:
   1. early competency determinations.
   2. jury selection.
   3. insanity defenses.
   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3

15. ______ is a progressive neurodegenerative disorder with symptoms that include loss of empathy, disinhibition, compulsive acts, and transgression of social norms.
   a. Parkinson disease
   b. Hodgkin disease
   c. Cerebral palsy
   d. Frontotemporal dementia

16. Some people with epilepsy are known to display aggressive, assaultive behavior.
   a. true
   b. false

17. Which region of the brain is critical to distinguishing moral issues, exercising inhibition, and making decisions concerning moral issues?
   a. paralimbic
   b. brain stem
   c. prefrontal cortex
   d. amygdala

18. Neuroprediction refers to:
   a. the use of genetic twin studies to determine what traits will appear in the next generation.
   b. predicting the effect of abuse on brain volume changes in children.
   c. an effort to gauge the likelihood that a convicted person will harm someone else.
   d. planning treatment regimens for incarcerated offenders before they are released.

19. Offenders with specific patterns of error-related brain activity seen during a test of impulse control were approximately _____ times more likely to be rearrested than offenders more capable of impulse control.
   a. 2
   b. 3
   c. 4
   d. 5

20. When researchers used EEG, MR imaging, computed tomography, and neuropsychological testing to evaluate 31 prisoners, results showed widespread dysfunction and abnormalities in all test subjects.
   a. true
   b. false