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The brain and crime

Abstract

This paper is a review paper examining relationships between the brain and crime. Based on a literature review from searches of two academic databases—ProQuest and Academic Search Complete—the paper summarizes what has been demonstrated about the brain and crime from the most recent peer-reviewed journal articles on the subject matter. The paper begins with a discussion of key brain structures and establishes their role in human behavior, and then the literature review provides details on how those structures are involved in crime based on the studies. Included in the analysis are studies on brain deficits, brain dysfunction, Traumatic Brain Injury (TBI), and Adverse Childhood Experiences (ACEs).

Keywords: Brain; Crime; Brain dysfunction; Traumatic brain injury; Adverse childhood; Experiences.

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Introduction

Studies routinely show that delinquency and crime are associated with numerous factors identified by psychology (e.g., low empathy and fear, impulsivity), as well as sociology (e.g., antisocial peer affiliation, lack of positive parenting practices, low neighborhood cohesion) [7]. Yet, there is also important information identified by biology, including many findings related to antisocial behavior and the brain [30]. Importantly, there is evidence that brain structure and function is related not only to street crime but also juvenile delinquency [36] and some forms of white-collar crime [65].

Any examination of the brain and behavior should begin with the basics. In this section, the author identifies key structures of the brain and discusses their main roles in behavior. Some commentary about their involvement with aggression and violence is provided, as an introduction to what will be examined through research in the literature review of the paper.

The brain first can be divided into the cortex and subcortex. The cortex is the outer layer of the brain (i.e., the cerebrum) and the subcortex is everything below that. The cortex is comprised of gray matter, made up of neurons that are involved in everything from sensation, perception, movement, and information processing. Below that is the white matter, which connects gray matter, and is involved in signal transmission of neurons that deliver neurotransmitters across brain connections called synapses. Cortical thickness is a measure of brain health, as it affects cognition and intelligence. Cortical thinning is a measure of a brain problem, suggesting possible signs of dementia, for example. Studies indicate the cortical thinning is associated with both criminality and victimization.

The cortex can be divided into four parts or lobes, each with its own specific functions. Most notable for aggression, violence, and antisocial behavior are the frontal lobe/prefrontal cortex and the temporal lobe/limbic system. The former make up part of the cortex while the latter is part of the subcortex. The fronto-temporal region is comprised of the frontal and temporal lobes, and together they are responsible for planning, judgment, personality, emotions, language, memory, and much behavior; it has also been linked to antisocial behavior.

The prefrontal cortex is involved in executive functioning such as decision-making, planning, goal-seeking behavior; and it helps regulate emotions stemming from the limbic system in the temporal lobes. Injuries to and dysfunction of the prefrontal cortex are associated with increased involvement in antisocial behavior. The orbitofrontal cortex, a region at the very front of the prefrontal cortex, is involved in decision-making, controlling impulses and regulating emotions, and processing rewards/ punishments. It helps guide motivation and adaptive or prosocial behavior and has been linked to antisocial behavior in cases where it is underactive or not functioning properly. Studies find that experiences such as childhood adversity is associated with cortical thinning in the right medial orbitofrontal cortex.

The dorsolateral prefrontal cortex, a top region of the prefrontal cortex, is also involved in executive function, including memory, planning, problem-solving, and cognitive control. Reduced activity or connectivity is linked to increased aggression. The ventrolateral prefrontal cortex, located below the dorsolateral cortex, is also responsible for executive functions, including goal-directed behaviors and emotional regulation. It plays a critical role in regulating aggression through its involvement in self-control and emotion regulation, which helps to inhibit aggressive impulses. Injuries and other dysfunctions to the frontal lobes and prefrontal cortex have been linked to aggression and violence.

The anterior cingulate cortex is connected to the frontal and temporal lobes, and is involved in cognition such as reward-based decision-making, motivation, learning, and impulsivity; reduced activation and structural abnormalities are associated with more impulsivity and aggression as well as with criminal recidivism. (Figure 1) illustrates some of the structures discussed.

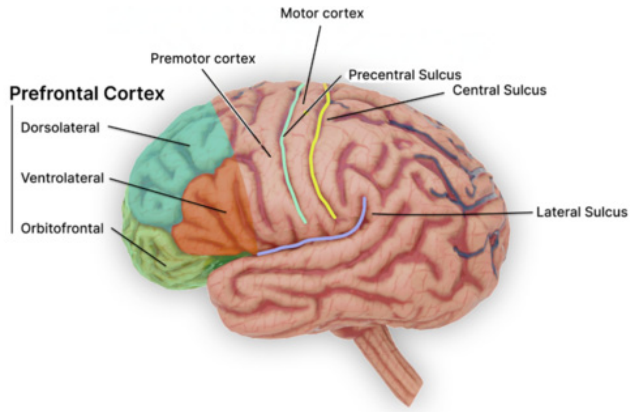

Figure 1: Structures of the cortex.
Source of image: https://en.wikipedia.org/wiki/Prefrontal_cortex

The subcortex includes many structures of the brain below the cortex. One is the thalamus, and thalamic volume has been implicated as relevant for antisocial behavior including violence. The thalamus is a sensory and motor relay station and is involved in attention, arousal, and sensory processing. The hypothalamus helps maintain homeostasis, which includes things such as body temperature as well as hunger, thirst, and sleep. It also helps regulate emotions. It does all this by linking the nervous system to the endocrine system through the pituitary gland and regulating the autonomic nervous system. Research shows that areas like the anterior hypothalamus and ventromedial hypothalamus are hubs that can trigger aggressive behavior, and that electrical stimulation of the hypothalamus can even produce aggressive actions.

The amygdala-hippocampal complex is important for emotion and memory, including emotional memories. For example, the amygdala processes emotion and the hippocampus handles episodic memory. The interaction between the two structures modulates how emotional experiences are encoded and recalled. For example, the amygdala can strengthen memories with emotional content, and the hippocampus can provide contextual details to the emotional response. The amygdala is also involved in fear and regulates anxiety and stress. Reduced volume of the amygdala is associated with psychopathy and aggression. A hyperactive amygdala that is not sufficiently controlled by the prefrontal cortex can produce poor emotional and behavioral regulation. Further, different sub-regions of the amygdala are involved in different kinds of aggression. The hippocampus is involved in memories and spatial cognition; reduced hippocampal volume is associated with aggression.

The superior temporal gyrus is involved in processing speech, yet increased activity in this region is found during aggression and reduced gray matter volume in this area if associated with aggression. Caudate nuceli are found in the basal ganglia and are involved in motor control and executive function such as decision-making, focus, learning, and emotions; larger caudate volumes correlate with higher levels of aggression. The HPA Axis is found in the brain stem and is involved in stress response, vigilance, arousal, and attention; high and low levels of HPA axis activity are found to be related to aggressive behavior. The Recticular Activating System (RAS) is made up of neurons in the brain stem that control arousal and goal-setting; dysfunction is linked to various neurological and psychiatric disorders. (Figure 2) illustrates some of the structures discussed.

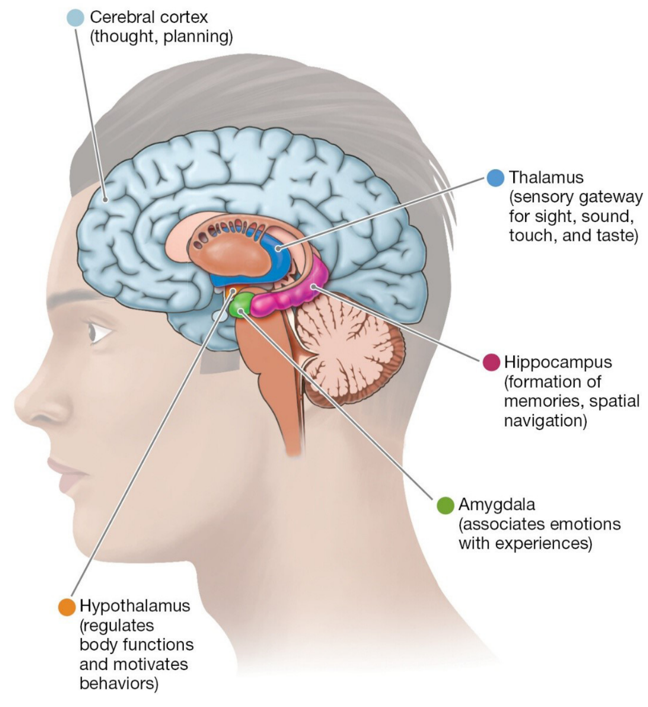

Figure 2: Structures of the subcortex.
Source of image: https://nerd.wwnorton.com/ebooks/epub/psychlife4/EPUB/content/2.2.3-chapter02.xhtml

The rest of the paper consists of a literature review based on database searches of the terms "brain and crime" using ProQuest and Academic Search Complete. The research focuses on many different areas of the brain and many different areas of inquiry.

Methodology

This is a review paper, aiming to discover what type of research has been recently conducted on the brain and crime in various academic fields of study. The author of this paper searched for peer-reviewed journal articles using the terms "brain and crime" using two databases—ProQuest and Academic Search Complete. According to the author's library website, ProQuest is "comprehensive database supporting research on crime, its causes and impacts, legal and social implications, as well as litigation and crime trends. As well as U.S. and international scholarly journals, it includes correctional and law enforcement trade publications, dissertations, crime reports, crime blogs and other material relevant for researchers or those preparing for careers in criminal justice, law enforcement and related fields." It covers research from 1981 until the present day. Meanwhile, Academic Search Complete contains "full text for over 8,500 magazines and journals, including more than 7,300 peer reviewed titles. Indexing and abstracts are provided for more than 12,500 journals. Covers a wide array of academic disciplines including biological sciences, economics, communications, computer sciences, engineering, language and linguistics, arts and literature, medical sciences and women's studies."

The goal of the paper is to provide a comprehensive summary of what has recently been discovered about the brain and its relationship to crime. According to Sataloff et al. [63]: "Review articles can be extremely valuable. They synthesize information for readers, often provide clarity and valuable insights into a topic." Owens [54] adds: "Well done systematic reviews, which include but are not limited to meta-analyses, offer an efficient way to evaluate large amounts of information for decision-makers in areas of research, policy … Systematic reviews can help us know what we know about a topic, and what is not yet known, often to a greater extent than the findings of a single study. The process is comprehensive enough to establish consistency and generalizability of research findings across settings and populations." This review paper demonstrates, for example, that the largest share of research on the brain and crime in the past ten years deals with Traumatic Brain Injury (TBI) and its relationship to aggression and violence.

Literature review

Some studies find evidence of brain deficits (e.g., reduced thalamic volume) in violent offenders [41]. According to Yang, Glenn, and Raine [78], "an increasing number of brain imaging studies have revealed structural and functional impairments in antisocial, psychopathic, and violent individuals." These include "the prefrontal cortex (particularly orbitofrontal and dorsolateral prefrontal cortex), superior temporal gyrus, amygdala-hippocampal complex, and anterior cingulate cortex." Damage to these regions of the brain often results in diminished self-control, a significant risk factor for criminality [61].

One notable case of murder and brain damage comes from that of NFL football player Aaron Hernandez, who died by suicide while incarcerated for first-degree murder; he was found to suffer from degenerative brain disease [33]. The link between brain damage and violence is well-known [41].

More generally, a targeted review which searched PubMed and Google Scholar for empirical studies that used brain imaging techniques in order to seek possible structural or functional differences between sexual offenders and a control groups summarized the structural and functional findings of 15 brain imaging studies; this included computed tomography, diffusion tensor imaging, magnetic resonance imaging, positron emission tomography, and functional magnetic resonance imaging. The authors write that the findings "suggest possible differences in brain size and gray matter volume, cortical thickness, white matter connectivity, and specific structural and functional differences among brain regions (fronto-temporal region, amygdala, prefrontal cortex, etc.)" [38].

Another study found that "pedophilic child molesters exhibit slower processing speed, nonpedophilic child molesters exhibit poorer semantic knowledge, and both molester groups exhibit executive weaknesses as compared to nonoffender controls" [66]. This supports their claim that evidence does exist that child molesters have "structural and functional brain adnormalities." Still another study demonstrated abnormal brain activity (i.e., cortical thinning in numerous areas of the brain) in pedophiles [45]. So, it is clear that brain abnormalities are related to sexual violence [6].

Brain research is also important for understanding differences between antisocial youth and prosocial youth. For example, brain differences are found in young people who make risky decisions and "healthy controls" [21]. Risky decision-making stems from diminished frontal lobe activity. Parts of the brain including the prefrontal cortex are highly involved in inhibitory control or what is referred to in criminological theory as low self-control [65]. Gillespie, Brzozowski, and Artur [28] add that: "The amygdala and prefrontal cortex are critically involved in the process of self-regulation, and neuroimaging and behavioural methods, including the role of executive functions, have been used to study abnormalities of prefrontal structure and function in individuals who display aggressive and antisocial behaviours. The functioning of these circuits is also influenced by activity of the autonomic nervous system, and a robust and consistent relationship has been observed between low resting heart rate and violent and non-violent crime" (p. 57). A study attempting to link low self-control in offenders to the brain found that, as should be expected, low self-control is associated with deviance and substance use problems, but also to measures of disinhibition, leading the authors to conclude that low self-control has "a prominent biobehavioral basis" [71].

Brain dysfunction and Traumatic Brain Injuries (TBI). The term brain dysfunction refers to a problem with normal brain function caused by things such as head injuries. Strong links exist between brain dysfunction, violence [55], and criminal recidivism [42]. An extensive review of 40 years of empirical studies found that, whereas the incidence of neuropathology in the general population is about 2%, "the relative ratios … among violent offenders range from highs or 47:1 for homicide offenders and 48:1 [for sex] offenders … 43:1 for juvenile offenders, 39:1 for assault offenders, and 33:1 for incest offenders" … but only "6:1 for 'one-time aggressives'" [55].

It is widely posited that head injuries are bad for the brain. One study of 25 children of Non-Accidental Head Injury (NAHI) found a "wide range of abnormalities and outcomes"—"Speech and language difficulties were present in 64% including autistic spectrum disorder. Cranial nerve abnormalities were present in 20%. Visual deficits and epilepsy compounded learning difficulties in 25% of survivors" [2]. NAHI is also referred to as acquired Brain Injury (ABI). A study of 729 women, 61% of whom experienced physical violence, found that 32% faced "a heightened risk of ABI" [51]. More on the link between victimization and brain injury will be addressed later in this paper.

In some instances, Traumatic Brain Injury (TBI) can produce brain dysfunction and TBI has also been tied to antisocial behaviors. Turner, Cook, Shi, Elton-Marshall, Hamilton, Ilie, Wickens, McDonald, Trajtenberg, Cusimano, and Mann [69] note that TBI is "characterized by a change in brain function after an external force or sudden movement to the head" and they note that TBI is "associated with risk-taking, impulsivity, psychological distress, substance abuse, and violent crime." Their study also links TBI to problem gambling behaviors.

Studies generally find that TBI is associated with violence including the likelihood of arrest for violent crimes [43], as well as sexually offensive behavior [3]. One study of more than 5,000 youth ages seven to 12 years of age found that those youth "who reported carrying a weapon, who were engaged in a physical fight and those who assaulted peers on school property … had statistically significantly higher odds of reporting a history of TBIs" [34].

One set of scholars states the relationship between Traumatic Brain Injury (TBI) and aggression and other outcomes this way: "Traumatic Brain Injury (TBI), a leading cause of both death and disability worldwide, is highly prevalent among individuals who intersect with the criminal justice system. TBI is associated with increased behavioural, psychological, or negative outcomes, such as higher rates of mental health problems, aggression, and violent offending that may lead to negative interactions with the criminal justice system, reincarceration, and recidivism" [9].

The mechanisms of TBI and criminality are now well-posited. For example, Waltzman, Daugherty, Haarbauer-Krupa, Zheng, Jorge, and Basile [16] write that a TBI can cause "neurological or neuropsychological changes and may also lead to various symptoms that affect a person's cognition, mobility, behavior, and mental health." Pierre and Parente [56] add that TBI populations are "predisposed to aggressive tendencies because the injury enables impulsivity, loss of self-control, and the inability to modify behaviors," behaviors which themselves "lead to criminal involvement." This is largely due to executive control impairments associated with frontal lobe dysfunction, which is found to be associated with various crimes including battering behaviors [12].

Additionally, Durand, Chevignard, Ruet, Dereix, Jourdan, and Pradat-Diehl [19] report that TBI "can lead to cognitive, behavioural and social impairments." Their review of 33 papers—the majority of which were on prison populations in Australia, Europe, and the United States—found a prevalence rate of TBIs between 10% and 100% with an average of 46%. Several comorbidities were noted, including mental health problems and drug use. Pierre and Parente [56] note that "the majority of the prison population has sustained at least one TBI in their lifetime." Indeed, a very high portion of prison inmates are found to suffer from TBIs [13].

Brewer-Smyth and Burgess [5] add that: "Frontal lobe damage from TBIs may decrease ability to control behaviors associated with emotions from the limbic system." Their study of homicide offenders (n=9), other violent crimes (n=51), non-violent criminals (n=49), and noncriminals (n=12) found: "Homicide perpetrators suffered the most Childhood Sexual Abuse (CSA); most recent abuse; had the most neurological histories, mainly Traumatic Brain Injuries (TBIs); most health care access for abuse-related injuries; lowest AM And PM salivary cortisol; and greatest proportion who committed crime under the influence of alcohol.

According to Williams, Mewse, Tonks, Mills, Burgess, and Cordan [75], TBI "can lead to cognitive, behavioural and emotionally difficulties." Their study of 196 offenders found that more than 60% reported head injuries and: "Reports consistent with TBI of various severities were given by 65%. Of the overall sample, 16% had experienced moderate-to-severe TBI and 48% mild TBI." The study also found: "Adults with TBI were younger at entry into custodial symptoms and reported higher rates of repeat offending."

Studies of outcomes of TBI find it to be associated with increased rates of both violent crime and suicide [35,43]. A study of TBI found that lifetime experience of TBI was associated with increased violent offending, a relationship that was meditated by "hostility," defined as a "cognitive process characterized by unfriendliness, opposition and assumptions of malintent by others that may result in other-directed affective states of anger and frustration" [76]. Still another study of delinquent youths who were followed into early adulthood to estimate if self-reported TBI is associated with violence; results suggest it is [53].

Another study found that TBIs were one of the reasons that females committed murders. The authors note the logic of their finding, writing: "Frontal lobe damage from TBIs may decrease ability to control behaviors associated with emotions from the limbic system" [5], as noted earlier. As one example, consider damage to a white matter area called the right uncinate fasciculus. The structure connects the right anterior temporal lobe with the right orbitofrontal cortex and mediates socioemotional processing, empathy, emotion recognition, and face processing. Damage reduces one's ability to regulate emotions, feel empathy, and process consequences, likely reducing self-control [39].

Umbrass [70] notes that TBI "may affect cognitive processes related to psycholegal capacticites." His analysis of 80 US service (i.e., military) members found that 20% had suffered TBIs, and that TBI "is common among service members charged with criminal offenses." Pierre and Parente [56] report that TBI "enables impulsivity, loss of self-control, and the inability to modify behaviors"; these are associated with criminality. They also claim that "the majority of the prison population has sustained at least one TBI in their lifetime." Another set of scholars point out the significance of TBIs for kids, noting: "Traumatic Brain Injuries (TBIs) are linked to a range of consequences salient to adolescent development and well-being, such as impulsivity, academic abilities, and emotional processing" [47].

Studies find that TBI is associated with outcomes such as drug use (i.e., alcohol and marijuana) and criminal justice involvement (i.e., number of times in custody and total time spent in jail) [20,57]. TBI is also found to relate to greater severity and earlier onset of drug use, as well as an earlier age at first use predicted greater aggression [25]. A study of more than 200 people with histories of major mental illnesses and sexual behavior problems, including 25 people who were in secure forensic care with a history of Traumatic Brain Injury (TBI), plus 118 people with intellectual disability but no known TBI, and then 103 people with neither intellectual disability nor TBI, found the following: (1) "those with TBI more closely resembled participants with intellectual disability in their educational experiences"; (2) those with TBIs "were nearly equally likely to have never worked, worked sporadically, or worked for a year"; (3) "those with TBI were more similar to those with neither TBI nor ID [intellectual ability] with regard to similar and higher rates of psychotic symptoms and lower occurrences of ADHD or self-harm behaviors in comparison with those with ID and no TBI. However, persons with TBI evidenced significantly higher rates of substance abuse than either of the other groups"; (4) "those in the TBI group were significantly more likely to be arrested, which is consistent with findings from others that persons with TBI in forensic care demonstrated greater justice system involvement"; and (5) "those with a history of TBI committed a wider and more variable range of sexual offenses (e.g., more often sexually victimizing males, females, and both genders)" [44]. Brain injury is one of several potential sources of bad behavior.

TBI and victimization. There is a correlation between TBI and victimization [15]. Specifically, being the victim of violence is found to be associated with a higher likelihood of experiencing a TBI, including intimate partner violence [14,48] — since victims "often experience violent blows to the head, face, and neck and/or strangulation that result in brain injury" [1]]. The same is found for sexual violence [73], and even violence in prison [23]. TBI is also found to lead to PTSD and depression [10]. In this way, perhaps violence begets violence.

Violence victimization is also reportedly tied to concussive injuries [27]. For example, a study of nearly 1,500 people found higher rates of concussive injuries for victims of interpersonal violence victimization, as well as emotional abuse, physical abuse, and sexual assault [27]. One study of 86 women who were victimized by violence found that 24% had mild traumatic brain injuries and they were more likely to suffer from post-concussion physical symptoms which impacted cognitive functioning [77]. Concussions are reportedly associated with future violent behavior [60].

Other brain differences have been associated with criminal victimization, including in sexual assault victims. One study of 27 victims found that, relative to the control group (n=20), "the survivor group had lower levels of morning cortisol and showed attention deficits," plus "a lack of deactivation in the dorsal anterior cingulate cortex when processing emotional material relative to neutral material" [58].

Another study found a relationship between sexual abuse, PTSD, and changes to the brain. Specifically, an analysis of ten children with sexual abuse-related PTSD found "changes in activity and connectivity in regions involved in emotional regulation (amygdala and dorsal prefrontal cortex) and semantic memory (temporal and ventrolateral prefrontal regions)" [17]. Another study of PTSD-related severe childhood sexual abuse demonstrated "smaller amygdala, hippocampus, anterior cingulate, and thinner prefrontal cortex, but normal thalamus," as well as a relationship between "symptoms of PTSD and sizes of right brain structures including smaller amygdala but larger hippocampus and anterior cingulate" [49].

Sheffield, Williams, Woodward, and Heckers [64] note that "total gray matter volume [is] inversely correlated with the severity of childhood sexual abuse" most notably "in the prefrontal cortex where volume [is] negatively correlated with sexual abuse severity." Another study linked childhood abuse to brain changes (i.e., smaller hippocampal volumes) [79].

Adverse childhood experiences. It is well known that Adverse Childhood Experiences (ACEs) are associated with changes to the brains of children [3,74]. ACEs are found in studies to be fairly common. For example, a study of nearly 20,000 six-to 17-year-old children found that about 23% had experienced at least one ACE, 10% had two ACEs, 6% had three ACEs, and 7% had four ACEs [8]. And the US Centers for Disease Control and Prevention (2025) reports that: "ACEs are common. Three in four high school students reported experiencing one or more ACEs, and one in five experienced four or more ACEs."

A study by those scholars of 149 youth ages 8-17 years with (n=75) and without (n=74) exposure to physical and sexual abuse and domestic violence found "reduced hippocampal and amygdala volume as potential mechanisms of stress sensitization to depression following exposure to violence," which "confer vulnerability to stressful life events among children who have experienced violence."

Another study found that childhood adversity—including neglect—was associated with cortical thinning in the right medial orbitofrontal cortex [24]. Still another study, this time of 265 people, found that those "with greater than two ACEs had smaller [anterior cingulate cortexes] and caudate nuclei than those without ACEs" [11].

Interestingly, ACEs and TBIs are related [3]. One study demonstrated that children "with four or more ACEs were 1.79 times more likely to have experienced a TBI compared to those with zero ACEs" [8]. TBI in childhood is then related to increased odds of problematic drug use, as well as conduct problems and police contacts [37].

An example of highly problematic ACEs includes sexual abuse victimization. And research shows: "Childhood sexual abuse may result in hyperactivation of the HPA axis, with amygdala hyperfunction, and decreased activity of the hippocampus (defective glucocorticoid-negative feedback). The early stress has been associated with increased plasma concentrations of proinflammatory cytokines, increased, and prolonged secretion of CRF (corticotropin releasing factor), and excessive or insufficient cortisol. Childhood sexual abuse has been associated with dysfunction of immunological and neuroendocrine response. There are activations of the HPA axis, the proinflammatory cytokine (IL-1, IL-6, and TNF-α) production from macrophages, the autonomic nervous system, and the amygdala - hippocampus complex" [52].

Child abuse clearly negatively impacts the brain of children [40]. According to Heany, Groenewold, Uhlmann, Dalvie, Stein, and Brook (2018:49): "Childhood maltreatment, including abuse and neglect, may have sustained effects on the integrity and functioning of the brain, alter neurophysiological responsivity later in life, and predispose individuals toward psychiatric conditions involving socioaffective disturbances." A meta-analysis conducted by these researchers included 17 functional magnetic resonance imaging studies reporting on data from 848 individuals that were included in a meta-analysis of whole-brain findings. According to the authors: "Adults exposed to childhood maltreatment showed significantly increased activation in the left superior frontal gyrus and left middle temporal gyrus, and decreased activation in the left superior parietal lobule and the left hippocampus … The findings suggest that childhood maltreatment has sustained effects on brain function into adulthood, and highlight potential mechanisms for conveying vulnerability to development of psychopathology" (p. 49).

Edwards [22] agrees with the sentiment that ACEs directly impact the brain, writing that "the parts of the brain affected by sexually traumatic experiences in childhood are … linked to many physical and psychological problems, such as depression, posttraumatic stress disorder, somatic complaints and suicide. Neuroimaging studies have provided a breadth of evidence that childhood sexual abuse is related to structural changes in the brain. Taken together, childhood sexual abuse affects brain development, leading to differences in brain anatomy and functioning that have lifelong consequences for mental health" (p. 55).

Post Traumatic Stress Disorder (PTSD) results from intense stresses including ACEs. A study of people with PTSD found they "had smaller amygdala, hippocampus, anterior cingulate, and thinner prefrontal cortex but normal thalamus. Further analyses within the PTSD group suggested an association between symptoms of PTSD and sizes of right brain structures including smaller amygdala but larger hippocampus and anterior cingulate. Thinner right prefrontal cortex and larger right thalamus seemed to be related to denial and response prevention, respectively. Being related to both hemispheres, dissociative amnesia was negatively associated with proportion of the right amygdala to right thalamus and to both left and right prefrontal cortex. Suggesting a neuro-protective effect against traumatic stress at least through adolescence, depersonalization-derealization and identity alteration were correlated with thicker left prefrontal cortex. Unlike the lateralization within PTSD group, correlations between regions of interest were rather symmetrical in controls. The graded response to stress seemed to be aimed at mental protection by lateralization of brain functions and possibly diminished connection between two hemispheres" [49].

Abuse and neglect impact areas of the brain involved in arousal control and executive function [29]. The authors write: "The main systems for arousal control, threat perception, attachment and social functioning exist in the two more primitive areas of the brain, the reticular activating system and the limbic system. The amygdala in particular plays an important role in modulating vigilance and generating negative emotional states and, if dysregulated, can play an important role in problems with arousal and disturbance of interpersonal relations" [18]. The prefrontal cortex, which is important for development of the executive functions crucial for complex social development, problem solving and development of coping strategies, has the most protracted development, and shows continued growth throughout adolescence and early adulthood [26]. Areas of the brain that have to do with arousal control and emotional regulation in the limbic system of the brain also continue to develop well into adolescence.

Bremner and Vermetten [4] note that: "Early stressors such as maternal separation result in lasting effects on stress-responsive neurobiological systems, including the Hypothalamicpituitary-Adrenal (HPA) axis and noradrenergic systems. These studies also implicate a brain area involved in learning and memory, the hippocampus, in the long-term consequences of early stress. Clinical studies of patients with a history of abuse also implicate dysfunction in the HPA axis and the noradrenergic and hippocampal systems" (p. 113).

Research also now demonstrates clear relationships between stressors associated with, for example, urban life, and brain (dys)function [62]. These scholars write that the "structural pressures of poverty, discrimination, concentrated violence, and high rates of emotional abuse lead to stress on the brain in the form of high allostatic load, over-activation of the hypothalamic-pituitary-adrenal axis, and an imbalance of cortisol levels. These stressors, subsequently, lead to violence and aggression often associated with delinquent groups and gangs" (p. 69).

Conclusion

As the organ of behavior, it is obvious that the brain is involved in all behavior, and research reviewed in this paper shows that the brain is heavily involved in aggressive, violent, and criminal behaviors. Specific findings illustrated in this paper include:

- Cortical thinning is associated with criminality and victimization, including various sexual offenses, and Adverse Childhood Experiences (ACEs) are associated with thinning of the right medial orbitofrontal cortex;
- Thalamic volume is implicated as relevant for antisocial behavior including violence;
- Injury to the prefrontal cortex, particularly the orbitofrontal and dorsolateral prefrontal cortex, is associated with increased likelihoods of violent behavior;
- Traumatic Brain Injury (TBI) is associated with violent and recidivist behaviors, plus problems with gambling, carrying weapons, physical fights and assaults, mental health outcomes and suicide, cognitive and intellectual problems, problems in school and work, hostility, drug use, and increased criminal justice system involvement (e.g., odds of incarceration);
- Damage to the right uncinate fasciculus is found to lead to reductions in one's ability to regulate emotions, feel empathy, and process consequences, likely reducing self-control;
- There is an ironic link between criminal victimization and TBI, where victims of various forms of crime are more likely to experience TBI, thereby increasing their odds of violent behavior;
- Underdeveloped frontal lobes are associated with impulsivity or low self-control and thus aggressive behavior;
- Reduced activity or connectivity of the dorsolateral prefrontal cortex is associated with aggression;
- Reduced activation and structural abnormalities in the anterior cingulate cortex is linked to impulsivity and aggression as well as with criminal recidivism;
- The anterior hypothalamus and ventromedial hypothalamus are hubs that can trigger aggressive behavior; electrical stimulation of the hypothalamus can produce aggressive actions;
- Reduced volume of the amygdala is associated with psychopathy and aggression; meanwhile, a hyperactive amygdala that is not sufficiently controlled by the prefrontal cortex can produce poor emotional and behavioral regulation or low self-control. Further, different sub-regions of the amygdala are involved in different kinds of aggression;
- Increased activity in the superior temporal gyrus is found during aggression and reduced gray matter volume in this area if associated with aggression;
- Larger caudate volumes correlate with higher levels of aggression;

- High and low levels of HPA axis activity are found to be related to aggressive behavior; and
- Dysfunction to the Recticular Activating System (RAS) is linked to various neurological and psychiatric disorders and may thus be associated with some forms of criminal behavior.
- Criminological theory must begin to pay attention to the research being done by brain scientists who have clearly demonstrated the relevance of the brain for criminal behavior. To make studies logically complete, brain studies should always include environmental influences, as well, for it is the interaction of the brain and environment that determines human behavior.

Declarations

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Conflict of interest: There are no conflicts of interest in this paper.

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