Neurobiological Aspects of Violent and Criminal Behaviour: Deficits in Frontal Lobe Function and Neurotransmitters[1]

K. Jayasankara Reddy,[2] Karishma Rajan Menon,[3] & Unnati G. Hunjan[4]
CHRIST (Deemed to be University), Bengaluru, India

Abstract

Many neurobiological abnormalities have been reported in patients with violent and criminal behaviour. Strong associations exist between aggressive/violent behaviour and brain dysfunction. Also, many studies support an association between frontal lobe dysfunction and increased aggressive or antisocial behaviour. The focal orbitofrontal brain injury is specifically associated with increased aggression. Deficits in frontal lobe executive functions may increase the likelihood of future aggression, but as of now, studies have reliably demonstrated a characteristic pattern of frontal network dysfunction predictive of violent crime. The evidence is strongest for an association between focal prefrontal damage and an impulsive subtype of aggressive behaviour. This paper covers dysfunctions in these regions contributing to severe aggressive and violent behaviour, as well as neurotransmitters implicated in the same.

Keywords: Frontal Lobe, Orbitofrontal, Ventromedial Limbic System, Serotonin, Dopamine, Testosterone, Criminal Behaviour, Aggression.

Introduction

Aggression is an extremely important problem currently, both in the context of society as well as a clinical problem. However, the assessment and classification of aggression can become difficult due to the phenomenological as well as biological differences in the types of aggression. It has been majorly categorized into two types, the predatory subtype is a structured behaviour which is directed towards a goal, wherein the being has a calm state of mind. The defensive type is contrasted with this since it is unstructured and an arousal of emotion and vocalizations is present with a feature of fear

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[2] Associate Professor, Department of Psychology, CHRIST (Deemed to be University), Bangalore, India. Email: jayasankara.reddy@christuniversity.in

[3] Master's Student, School of Psychology, The University of Sydney, Australia. Email: karishma.rajan@gmail.com

[4] Assistant Professor, Department of Psychology, CHRIST (Deemed to be University), Bangalore, India. Email: unnati.hunjan@christuniversity.in

and hostility. In antisocial personalities, the predatory kind of aggression is often found, whereas, in most other scenarios, the person gets aggressive in reaction to a threat, is perceived by him. This perception is then dependent on his information processing (Elst et al., 2000).

Due to the advances in technology, researchers have been able to establish a clear link between abnormalities in brain functioning and the increase of incidences of crime and violence. A lot of recent neuroimaging studies have also contributed to the findings. As the brain is a complex organ, certain regions are dedicated to specific functions. Areas, particularly in the frontal regions of the brain, have been found to be involved in cases of criminal behaviour.

One of the oldest recorded cases of brain lesions causing behaviour and emotional dysregulations is that of Phineas Gage. A railroad accident caused permanent damage to the orbitofrontal and ventromedial regions of his frontal lobe resulting in personality changes in him such as irritability, anger problems and issues in handling responsibilities and jobs.

Another case found that a16-year-old high school boy started exhibiting violence towards his mother following an injury to his frontal regions and portions of his brain stem. He later attacked a woman and her young son, whereby the defendants argued for his case by justifying that the actions were caused due to brain impairments. This case is one of the many that uses brain imaging results to not only explain and substantiate criminal behaviour by linking dysfunction and violence but also brings into light the significance of such evidence during criminal trials (Davis & Traynor, 2012; Schiltz, Witzel, Bausch-Holterhoff & Bogerts, 2013).

Even though the majority of the brain imaging studies provides us with correlation data and not causation, studying particular case studies can give us deeper insight into causation as well. One of the well-suited examples is that of Michael, a 40-year-old school teacher, who was happily married to his wife and was raising his stepdaughter lovingly. He was never accused of defiant, hostile or inappropriate behaviour. However, suddenly he had started getting aggressive with his wife and made sexual advances towards his little daughter and others he met in social situations. He was even caught with pornography at his school and later convicted for his inappropriate sexual behaviour and aggression.

He was suffering from persistent and highly painful headaches. An MRI scan was done to check this persistent headache and it revealed a tumor in his orbitofrontal cortex. He underwent surgery and once a tumor was removed, his normal behaviour resumed. A few months later Michael displayed his previous defiant behaviour once again and on further examination it was found that the tumor had returned. On removal for a second time, his behaviour returned to normal again and he has been living happily with his family (Glenn & Raine, 2014). So even though causation cannot be defined from brain scans, this case example does provide us with evidence of the role of the frontal lobe in aggressive and defiant behaviour.

Role of the frontal cortex

The frontal lobe's role involves various widely known and studied functions such as language and motor functions but it recently it has also been found to play a role in a myriad of other processes. These include social reasoning, morality, affect, personality, self-awareness, executive functioning and other cognitive processes as well (Chayer &

Freedman, 2001). These findings are important to gauge the role frontal lobe plays in a different situation.

To understand the impact of neuropathological abnormalities, it becomes imperative to explore the regions of the brain that regulate aggression and other violent behaviour. The relationship between violence and hyperactivity/ aggression can be traced back to early childhood years (Seguin, 2009). The frontal regions of the brain have been particularly implicated in incidences of aggressive behaviour. Higher incidences of aggression have been reported in patients who have had injuries to the frontal regions, particularly the orbitofrontal and ventromedial regions. There have also been instances of reported 'acquired antisocial personality disorder' resulting from damage to unilateral orbitofrontal regions (Seguin, 2009). The development of borderline personality disorder has also been linked to the early impairment in the functioning of this region (Blair, 2004).

The Ventromedial prefrontal cortex plays a role in reinforcement related activities while the orbitofrontal cortex regulates the choice of desirable outcomes and the dorsolateral prefrontal cortex monitors and resolves the response conflict (Blair, 2008). An impairment in these structures can lead to impaired decision making, leading to frustration and the aggression that arises from it (Blair, 2008). When aggression and violence scales were administered to subjects, a higher score was obtained for subjects with frontal lobe lesions especially the ventromedial region as compared to normal control subjects (Brown *et al.*, 1996).

Injuries to the frontal lobe have also been found accountable for high impulsivity, and lack of sensitivity and inhibition in individuals. In general frontal lobe lesions do not predict violent crime, but may increase the risk of violence by 10-20% over the base rate for a given population (Brower & Price, 2001). Aggression and disinhibition was also found to stem from damage to the anterior cingulate region which plays a role in monitoring conflict, error processing and avoidance learning, as well as damage to the dorsolateral prefrontal cortex which has been linked to features of antisocial personalities like poor impulse and behavioural control (Glenn & Raine, 2014).

The frontal lobes also play an executory function wherein social cues are processed and individuals engage inappropriatebehaviour based on these cues. This helps the individual move away from situations that may provoke aggressive behaviour. Any damage to the said region may result in them gauging the situation differently leading to poor decision making and conflicts (Blair 2001 as cited in Aguiar 2013). When the region of the ventral frontal lobe is damaged, it is observed that this impairment can lead to misidentification of emotional expressions, both facial and vocal, along with socially inappropriate behaviour. A very strong positive correlation was also found between the extent of their disinhibition, behaviour related problems and impaired emotional experience (Hornak, Rolls, & Wade, 1996).

The somatic markers hypothesis also explains that impairments or lesions in the ventromedial regions in the brain result in characteristic behaviours such as the inability to learn from mistakes and difficulty assessing emotional reactions (Bechara, Damasio & Damasio, 2000). Brain injury to this region resulted in hampered decision making, autonomic reactivity reduction to socially meaningful stimuli and psychopathy (Damasio, 1994). But, one needs to understand that there are other factors such as premorbid personality as well as hormonal regulation prior to the injury responsible for individuals acting out aggressive tendencies (Aguiar 2013).

Recent studies on frontotemporal dementia patients suggest a loss of moral behaviour with the disease on the right side of the brain. Affiliative traits including warmth and empathy may rely on right ventromedial prefrontal and anteromedial temporal regions (Sollberger et al., 2009). The sociopathic behaviour can result from damage in these regions combined with right orbitofrontal damage causing disinhibition (Mendez, 2010).

Results from brain imaging studies

The importance of brain imaging studies is brought to light through the famous case of Brian Dugan, a convicted rapist, and murderer, in 2009. The murderer's ability to control his hostile impulses was taken into consideration, in this case. Based on his clinical contact, the expert testified that he was a psychopath, a condition in which he has impaired empathy, regret and control, which makes him more likely to commit crimes and display aggressive behaviours (Wolf & Koenigs, 2015).

The expert also testified that the murderer's fMRI brain scans revealed that there was diminished activity in the key areas of his brain thus affecting the regulation of his behaviour and impairing his impulse control. This case was the first time the testimony of an expert based on functional magnetic resonance imaging data (fMRI) was accepted and taken into consideration at the U.S. court of law during a criminal trial. It is projected as the landmark for the intersection between neuropsychology/neurosciences and the law (Wolf & Koenigs, 2015).

Brain imaging studies have paved way for establishing clear links between brain dysfunctions and aggressive behaviour. Foreman (2002) highlights a study conducted on healthy volunteers and implicated murders where PET scans revealed that the brains of the murderers had lower glucose metabolism indicating that the regions responsible for inhibitory behaviours were not adequately functioning. Brower and Price (2001) conducted an extensive methodological review study highlighting that PET scan studies showed decreased cortical blood flow in patients with forensic psychiatric problems as compared to healthy controls and they were associated with impulsive and violent behaviour.

A study used positron emission tomography to study the glucose levels in the prefrontal and subcortical regions of the brain in murderers of two kinds, the first was the predatory kind that involved well-planned and structured hostility, the other was affective aggression which involved unstructured affective arousal and aggression. The affective kind was found to have a lesser prefrontal functioning, greater subcortical functioning in the right hemisphere and also a lesser ratio of prefrontal/subcortical in the right hemisphere. This study is important as it evidenced that affectively motivated and impulsive aggression made it difficult for the murderers to control or regulate their hostile impulses which rise from the subcortical regions and this was due to the deficient regulation of the prefrontal cortex (Raine et al., 1998).

MRI and CT scan results also showed brain abnormalities in regions such as the frontal and parietal cortex, and the third ventricle (Schiltz et al., 2013). The largest reduction in the structure and function of the frontal lobe, particularly the orbitofrontal cortex, anterior cingulate cortex, and dorsolateral prefrontal cortex was evidenced by a meta-analysis of structural and functioning imaging studies of antisocial individuals. It was also found that head injuries which gave rise to antisocial personalities in normal and healthy people, were often preceded by injuries to the frontal lobes, particularly the orbitofrontal cortex (Glenn & Raine, 2014). In psychopaths, MRI scans have revealed structural and functional abnormalities in areas of the brain that play a role in cognition, affective and social functioning. The functional connectivity between the anterior cingulate cortex and the insula has also found to be impaired (Wolf & Koenigs, 2015).

MRI scans also revealed very low frontal lobe activation in individuals that displayed aggressiveness compared to the control group (Mathews et al., 2005). In patients with temporal lobe epilepsy, these scans showed a reduction in the neocortical grey matter in the frontal lobe which led to aggressive episodes (Woermann et al., 2000). Functional imaging studies have revealed that ventromedial and orbitofrontal lobes play a role in regulating the physical act of aggression. It was found that the ventromedial region played a role in inhibiting aggression of the physical kind and also helps with self-regulation (Séguin, 2009).

On the other hand, the orbitofrontal cortex is not involved in the inhibition of reactive aggression per say, even though it does play a major role in the variation of reactive aggression. The probability of a person to display reactive aggression is modulated by this region wherein it may increase or decrease this probability based on the environmental presences of the social cue (Blair, 2004).

MRI studies have found links between psychopathy and abnormalities in the cortical as well as subcortical regions of the frontal lobe and temporal lobe. The functional connectivity between the amygdala and the ventromedial prefrontal cortex is reduced, as observed during tasks involving moral judgment, in psychopaths. Their brains when scanned using fMRI, showed various similarities to the brains of patients who had suffered from neurological damage to the ventromedial prefrontal cortex (Wolf & Koenigs, 2015).

Serotonergic neurons also project to the orbitofrontal cortex, and patients with impulsive aggression show decreased orbitofrontal metabolism on PET in response to serotonergic stimulation. The new neuroimaging studies showed increased orbitofrontal metabolism on PET and clinical improvement after 12 weeks of fluoxetine in impulsive aggression patients. The serotonin may facilitate prefrontal limbic inhibition (New et al., 2004).

Though it is imperative to not arrive at causal relations between these findings and the symptoms observed; a correlation may exist but correlation does not lead to causation and hence some amount of precautions need to be taken before arriving at definitive conclusions regarding causes of aggressive behaviours. However, these studies provide us a deeper understanding of the neurological markers that underlie the control of behaviour, hostility, empathy, and morality. They can then help understand psychopathy better and formulate treatment plans accordingly. The impaired regions of the brain can be targeted while also allowing us to gauge and predict such behaviours in the future.

Role of the limbic system

The prefrontal cortex is primarily responsible for actions that involve meticulous planning and decision making and as it an executive center, it also plays the role of directing one towards socially appropriate behaviour. The more emotion centric region is located much deeper within the brain known as the 'amygdala', which is responsible for actions involving 'acting on emotions' (Foreman, 2002).Fear conditioned responses have been linked to the functioning of the amygdala and any damage to this region is associated with individuals carrying out actions without worrying about the consequences (Sutton, 2016). Many impulsive actions were seen to rise from the 'amygdala, hypothalamus, and periaqueductal grey area' of the brain. Reduction in the grey matter in the frontal regions has also been implicated in patients suffering from an antisocial personality disorder (Seguin, 2009).

Reduced functioning of the amygdala, as well as a reduced volume, leads to individuals having blunted emotions and engaging in colder and calculated hostile behaviours (Yang, Raine, Narr, Colletti, & Toga, 2009), it also acts as a predictor for future violent behaviour (Glenn & Raine, 2014). Whereas those individuals who indulged in more hostile behaviours that are more reactive, displayed in increased reactivity of the amygdala (Coccaro, McCloskey, Fitzgerald, & Phan, 2007). Any kind of damage to the amygdala results in lessened fear lessened the perception of danger, and fear related facial expressions (Glenn & Raine, 2014).

There are many studies related to the role of the limbic system in crime and violence. Siever (2008) reviewed the literature and described a model in which violence occurs when temporolimbic "bottom-up" drives – prominently involving the amygdalae – cannot be inhibited by "top-down" prefrontal structures such as the orbitofrontal region and anterior cingulate cortices. There are many neuronal circuits between the limbic system and frontal lobe. The violence occurs when frontal inhibition cannot control limbic impulses; anger provocation and substance abuse are often involved.

The "dual process theory" can also be used to understand how emotional responses are interpreted. In the likelihood of a sensory event, pathways from the thalamus to the amygdala and to the frontal lobes are activated. The amygdala pathway is fast and triggers automatic affective responses whereas the frontal lobe pathway is slower and triggers controlled responses. The indirect cortical pathway tries to inhibit or suppress the direct amygdala pathway. Thus, the responses elicited from the amygdala, inhibits rational thoughts and any damage to the frontal regions may disrupt its activities to suppress the overly affective responses.

Role of neurotransmitters and hormones

There are many neurotransmitters that have been implicated in emotional and crime related behaviour. Studies conducted on experimental animals and case studies of individuals have shown that lowering serotonin levels in the brain can trigger aggressive behaviour. These lower levels can be caused by intake of certain drugs or even destruction of regions in the brain that is heavily concentrated with serotonin neurons. It is also implicated in not just acts of external violence but self-inflicted harm such as suicide (Badaway, 2003; Glick, 2015; Krakowski, 2003).

Serotonin was also found to inhibit both predatory and affective aggression. In the case of affective aggression, the serotonergic hypofunction is also found to have a hereditary basis, wherein it predisposes an individual towards hostility and impulsive behaviour. A reduction in serotonergic functioning is observed in the circuit involving emotional regulation, including the anterior cingulate cortex and the prefrontal cortex, which then leads to affective aggression. This dysfunction in the prefrontal cortex is also found to be comorbid with the affective aggression in various other conditions, namely, substance abuse and suicidal tendencies (Seo, Patrick, & Kennealy, 2008).

One of the hypotheses ascertaining the link between levels of serotonin and aggression is the 'low serotonin syndrome" implying that people in such a state have an "impulsive personality", and the "irritable aggression model" postulate that hypo-functioning of serotonin neurons lead to increased irritation and increased reactivity to triggers and situations(Badaway, 2003). Low levels of serotonin in the cerebrospinal fluid (CSF) are characteristic of a person who is impulsive and aggressive (Glenn & Raine, 2014). The functioning of the orbitofrontal cortex is also reduced when the levels of serotonin fall in the brain and impairment in this region is observed in people with antisocial behaviour patterns (Rubia et al., 2005).

Other neurotransmitters like catecholamines (dopamine, norepinephrine) may potentiate violent behaviour. Behavioural activation, motivation, and processing of rewards, all involve the dopaminergic system. It is also known to modulate aggression, wherein on the administration of dopamine receptor antagonists, it was found that impairment in the recognition and experience of aggressive behaviours and facial expressions takes place. A decrease in emotional regulation and increase in impulsivity is also found (Seo, Patrick, & Kennealy, 2008).

Pathological gambling can follow dopamine agonist treatment of Parkinson's Disease (PD) – pramipexole first reported (Driver-Dunckley, Samanta & Stacy, 2003) L-dopa can also produce impulse control dysfunction (ICD). Symptoms like aggression and hypersexuality may occur in ICD patients. Parkinson's disease patients are typically cautious, avoid risk, and seek less reward, consistent with loss of dopamine in the ventral tegmental area and decreased innervation of the nucleus accumbens (Stamey, & Jankovic, 2008). These studies clearly indicate dopamine may contribute to aggressive behaviour. Norepinephrine and Dopamine are known to play a role in inhibiting predatory aggression (Seo, Patrick, & Kennealy, 2008).

A link between the serotonin system and the dopamine system is also implicated. An impairment in the functioning of serotonin system and deficiencies in it may lead to an increased activity of the dopamine system and thus leading to impulsivity and aggression. Various animal studies have also led to similar findings but very few studies on humans exist, which look into this interaction. Thus the increased dopamine function may be secondary to the decreased serotonergic functioning. This increase in dopaminergic activity, owing to serotonin deficiency can further give rise to addictive behaviours, substance abuse as well as depression (Seo, Patrick, & Kennealy, 2008).

Seiver (2008) emphasizes on the maladaptive functioning of cholinergic activity, which can also trigger aggressive tendencies by activating the subcortical limbic regions of the brain. Gamma aminobutyric acid receptors have also been found to be linked with the same results. Reduction in oxytocin levels may also lead to increased feelings of mistrust and fear in individuals as it directly hinders amygdala functioning.

The oxytocinergic functioning may vary from individual to individual owing to the social events, stress, hereditary, seasonal changes, and many unknown causes yet to be studied. Lowered oxytocinergic functioning is connected to the increase in aggression, whereas a higher functioning is associated with inhibition of aggression. Thus aggression and levels of oxytocin are known to be negatively correlated (Jong & Neumann, 2017). In females, the effects of oxytocin can vary as it is known to be modulated by estrogen (Campbell, 2008). Most studies available on the role of oxytocin in aggression are related to maternal instincts and aggression as a function of protection of their offspring. Many studies on animals are also available but there is limited research on the effect of oxytocin levels on human aggression.

The prefrontal cortex plays a role in regulating the HPA (Hypothalamus-Pituitary-Adrenal) Axis, which responds to stress and releases the hormone, cortisol (Kern et al., 2008). Extremely low levels of cortisol during childhood were found to be linked with an increased amount of aggressive behaviour in the future, during adolescence or after a few years (van Bokhoven et al., 2005). As a person grows and develops, any kind of major psychological stress may cause permanent changes in the HPA axis of a person which then predisposes him to behave in an antisocial manner (van Goozen, Fairchild, Snoek, & Harold, 2007).

Cultural studies from over the world also associate more incidences of criminal behaviour with men and this stark difference is linked to the hormone testosterone which is abundant in males than females (Batrinos, 2012). Most common studies link castration to decreased aggressive behaviour as androgen production had a direct influence on the amount of aggression exhibited by the individual. Testosterone may influence aggressiveness but is more associated with dominance than aggression according to some studies (Glenn & Raine, 2008).

A causal relation between testosterone and aggression was found when it was administered to adult males and an increase in aggressive behaviour was observed (Glenn & Raine, 2014). A very informative study by van Bokhoven et. al. (2006) showed that when the testosterone levels were high between the age of 10 to 12, it could predict assaults and aggressive behaviours by the age 12 to 14. It could also predict violation of norms by the age of 16 and drug usage an abuse by the age of 19. There were also links found between higher testosterone levels and criminal activity in adulthood (van Bokhoven et al., 2006). Various social events and stimuli lead to a serotonergic response.

This serotonergic response can also be modulated by the level of testosterone and corticosterone (Summers et al., 2000).

Conclusion

Aggression and criminal activities are an alarming rise and have provided a critical area of concern. Many neurobiological abnormalities have been reported in crime and violent behaviour. The frontal lobes, particularly the orbitofrontal region and ventromedial region, are prominent because of their critical role in social cognition and impulse control. The limbic structures, particularly the amygdalae, are implicated because of their mediation of basic emotion and drive-related behaviour in the neuronal circuits. The structural and functional neuroimaging studies steadily add new data to establish these affiliations with more certainty. Understanding the role of neurotransmitters and hormones also help in demarcating normal functioning brain with persons suffering from dysfunction and maladaptive activities. Though these are crucial factors, it is also imperative to take into account an individual's genetic as well as psycho-social background to derive effective neuropsychological intervention and rehabilitation for persons convicted of criminal behaviour.

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