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The Neuroanatomy of Human Aggression

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Abstract

Animal behaviour has provided key insights into the neural circuitry controlling aggression and violence in human beings. The large evolutionary advances in the human brain have occurred in the frontal lobe, especially the pre-frontal cortex. However the same basic neuroanatomical structure and neural networks exist as are found in lower vertebrates and mammals. The two basic categories of aggressive behaviour, namely defensive rage and predatory behaviour are controlled mainly by the hypothalamus and amygdala with sensory input from the cerebral cortex aided by monoaminergic chemical release from the brain stem. It is hoped that recent advances in the understanding of the neuroanatomy behind aggression will lead to a reduction or at least modification of violent behaviour in mankind.

Key words: Neurocircuitry; hypothalamus; amygdala; violence; cerebral cortex

Introduction

Aggressive behaviour by human beings, particularly criminal violence, has long been difficult to understand and a troublesome aspect of human society (Maletsky 1973, Meloy 1997). Prevention is an idealised goal which requires detailed investigation of the complex psychological and anatomical evolution of the brain. Recent advances in neuroscience (Siegel 2009) and imaging of neuronal circuitry have provided further insight into the functioning of the human mind with possible diagnostic and treatment options for the future (Miczek 2007, Nelson 2007).

All animals have evolved specialised neural circuitry to execute and control aggressive behaviour. A locus deep within the hypothalamus that is involved in violent aggression in animals when stimulated was discovered several decades ago (Olds 1958, Moyer 1968). This same area when stimulated can produce other compulsive responses related to sexual behaviours, appetite and thirst.

The human brain has the same basic neuroanatomical structure and neural networks as in lower vertebrates and mammals.

Research into the neurocircuitry of violent behaviour and behavioural disturbance has largely come from animal studies and clear parallels exist with humans. Animals, including human beings, may display violent aggression instinctively to obtain food, defend themselves against perceived harm and protect their young depending on social and environmental circumstances. In species that are highly social, aggression is used to establish and maintain social order (Feshbach 1964). The rule of law in human society is a codified attempt to eliminate this form of aggression and is the basis of social order in modern communities.

The capacity for violent aggression is etched into our neuronal circuitry (Craig 2009) and has evolved through the struggle for survival over millennia. This circuitry can malfunction as a result of drugs (Negus 2014), disease (Bogerts 2017) or psychiatric impairment (Alpers 1940) and human aggression can be triggered by social events (Maletsky 1973). From a neuroscience perspective however only a few specific neural circuits are responsible for this conduct. This is seen when separate neural connections become activated.

It is now possible to identify rage and aggression circuits in the brain with techniques recently introduced. These include fibre-optic cameras threaded into the brains of animals which can observe neurons firing during a violent episode (Lin 2011). Also available is an experimental method to switch neural circuits on and off using optogenetics (Sun 2018). This has allowed identification of separate pathways for a response to an immediate threat as opposed to ones requiring deliberation.

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Neuroanatomy

The cerebral cortex is the fundamental structure of higher cognitive function and in particular the prefrontal cortex holds the essence of what makes us human. It integrates all the information needed to make complex decisions and regulate impulses. Needless to say the prefrontal cortex, apart from regulating executive judgements, plays a crucial role in the decision to signal or proceed with aggressive behaviour (Anderson 2018).

Deep in both temporal lobes is an almond shaped structure, the amygdala, which has widespread connections involved in fear, aggressive behaviour and associated emotional responses. These connections and their responses relate to the development of anxiety (Bogerts 2013).

The hypothalamus is the essential brain region maintaining the basic functions of temperature control, sexual behaviour, thirst and hunger. It also plays a key role in the sleep cycle, the release of hormones from the pituitary gland and aggressive behaviour. The hypothalamus, together with the amygdala, maintains these autonomous bodily functions without conscious control but can also generate the emotional drive for aggression (Alpers 1940, Reeves 1969).

The anatomical network of neurons and fibres interconnecting the amygdala, hypothalamus, hippocampus - which is vital for memory association, and cerebral cortex is the limbic system (Tonkonogy 1992). It combines threat detection, memory, emotion and learning into an appropriate response to acknowledge the particular social and/or environmental circumstances encountered.

Neurosurgeons have an intimate clinical knowledge of behavioural and metabolic disturbances when performing radical removal of tumours involving the hypothalamus (Tonkonogy, 1992). A particular case in point is removal of a craniopharyngioma from the third ventricle - the main anatomical structure involving the hypothalamus and limbic system.

Complications following radical excision of this benign tumour from the third ventricle may include rage, memory disturbance, hyperphagia, diabetes insipidus, abnormal temperature control, aggressive sexual behaviour and abnormal sleep regulation (Sughrue 2011). Somnolence, obesity, lack of impulse control and behavioural disturbances are the much feared outcome which may result from these complications (Reeves 1969).

Animal experiments

A landmark study in 2013 by Motta and colleagues, working with rats, showed the rapid synthesis of a protein deposited in the hypothalamus as a consequence of quick firing of neurons when the animal was provoked into an attack. The provocation was initiated by being threatened with an intruder. Remarkably this same process occurred after mating.

Other research groups (Lin and colleagues) confirmed the link to aggressive behaviour by inserting a fibreoptic camera into the hypothalamus of mice genetically engineered to make neurons emit flashes of light on bursts of electrical activity.

This behaviour requires sensory information to be received, processed and relayed to the hypothalamus after analysis by the cerebral cortex where there are specialised regions for vision, smell, sound and touch eventuating in conscious perception. This process takes time but there is a high speed sub-cortical pathway when faced with a sudden threat. It recruits the amygdala and produces an immediate "flight or fight" response.

The very fast response to a threat has evolved to transmit incoming sensory inputs directly to the amygdala before reaching the cerebral cortex and conscious awareness. The amygdala rapidly activates an aggressive response to the threat, usually detected via vision in humans but often by odours in animals (Kennett Sandnabba 1985). In the latter these relevant neurons may respond only to odours of the opposite sex.

The posterior nucleus of the amygdala has been shown to have neurons for hormone detection - mineralocorticoid receptors, which link stress to a trigger for aggression. When these receptors are blocked the previously aggressive rats become docile (Beiderbeck 2012). Clearly stress, with other factors, can lower the threshold for initiation of aggression.

Stimulation from electrodes placed in areas of the hypothalamus can induce copulation or aggression (Carlezon 2007). Lin and colleagues implanted microelectrodes into the hypothalamus of mice and found that certain neurons were very active during both fighting and mating. Some individual neurons fired during one behaviour and not the other, but some turned on during both activities (Falkner 2016).

Lin's group also threaded in a fibreoptic micro-strand to shine a laser beam that made genetically modified neurons generate electrical impulses in response to light (Sun 2018) and initiated aggression or copulation. The laser was used to drive neuronal firing at different frequencies and switch between patterns of behaviour.

Human Aspects

Jose Delgado, the late Spanish neuroscientist, working in the 1960s, placed an electrode into a woman's right amygdala and on stimulation she flew into a wild rage. The woman began smashing a musical instrument she was quietly playing against a wall until the stimulating current was turned off. There is little doubt that the amygdala can cause intensely violent emotions and is part of an expansive neural network that unleashes violent behaviour (Meloy 1988).

Delgado also stimulated the septal region of the sub-cortical limbic system in patients who were then suddenly overcome with strong sexual feelings ultimately building to an orgasm. As well as being active during sex and other rewarding activities this area can drive intense emotional responses including explosive rage.

The reward aspect of neuronal activity in this area was shown in rats in the 1950s when Olds and Milner implanted electrodes into their septal region. These rats would press a bar to deliver an electrical stimulus to these neurons to the point of exhaustion up to 5000 times per hour (Milner 1991).

Neurons in this part of the septal area (stria terminalis) also have receptors for the neurotransmitter noradrenalin which is released in the stress response. This brain region receives input from the cerebral cortex and connects to the hypothalamus for control of autonomic responses. This allows for release of the hormone oxytocin and the neurotransmitter dopamine both of which have important functions in regulating mood, anxiety and stress (Wise 1989).

Dopamine acts in the brain's reward centres, especially the nucleus accumbens (Beiderbeck 2012). These reward centres are another component of the aggression circuitry. Drugs of addiction such as cocaine and methamphetamine increase the reward modulating dopamine to trigger this circuitry as displayed by the violent, often irrational behaviour that can be seen in "ice" users (Negus 2014).

Feelings of superiority and dominance are the rewarding aspects of aggression and underlie bullying as well as criminal violence (Baumeister 1996). In pre-modern society this reward was likely the basis of a successful kill in the search for food. Today that need is somewhat fulfilled through recreational hunting, fishing and other sporting activities.

In the 1996 neuropathological post mortem study of the brain of a mass murderer, Charles Whitman, a small malignant glial tumour (glioblastoma multiforme) was found adjacent to the amygdala. In his suicide note he talked of overwhelming violent impulses with minimum provocation and had seen a number of doctors as well as a psychiatrist in the several months prior to the mass murder event. An autopsy was requested in the suicide note (Fields 2019).

The tumour conceivably could have contributed to his inability to control his emotions and actions (Ramsland 2005) but there was no conclusion in regard to his mental illness by the Texas Governor's Commission of Inquiry. Patients with mental disorders, other than paranoid schizophrenia, are no more likely than others to be violent (Bogerts 2013).

Classification of Human Aggression

This can be reduced into two main categories: defensive rage and predatory attack behaviour (Siegel 2009, Kingsbury 1997). These categories correlate well with animal studies (Meloy 1997).

Defensive rage is associated with fear and activated by a threat. This is associated with marked emotional and sympathetic activity, often impulsive, with minimal cortical involvement (Maletsky 1973). There is typically the single objective of removal or reduction of the real or perceived threat. In this process there is activation of the medial hypothalamus (Vitiello 1990).

Predatory attack behaviour is usually planned over a variable period of time and directed towards a specific person or group precipitated by a variety of motivating factors. It needs cortical involvement to be enacted but there is little in the way of sympathetic expression. It is associated mainly with activation of the lateral hypothalamus (Meloy 1997).

Clearly this categorisation has implications for criminal proceedings in many jurisdictions.

Sex Differences

Gender is the most important factor in predicting aggressive behaviour (Fields 2019) and there is a strong association between aggression and the male species. The relation between violence and sex has a strong biological basis most prevalent in animals. Hormonal influences on neural circuits controlling aggressive behaviour are an important component and probably the largest contributor (Book 2001).

However in social mammals, including most primates, the quest for food, the acquisition of a mate and defence of territory and tribe, promotes attributes that demand aggressive behaviour.

The neural circuitry explaining the disconcerting and puzzling association between sexual behaviour and violence has been investigated by Anderson and colleagues. They have shown how the same brain circuitry can be involved in the extreme opposite behaviours involved in love and hate. Both behaviours elicit intense arousal and potent feelings of reward. Male animals are more aggressive during the mating season and in nature aggression and mating are often interrelated. Both are regulated by similar influences from the environment and internal hormonal status.

Psychiatric Perspectives

Bernhard Bogerts, a German psychiatrist, used CT and MRI scans to examine the brains of both violent and nonviolent prisoners. There was a significantly higher incidence of brain abnormalities in violent offenders than in nonviolent ones or in a control group. The pathology showed up in the prefrontal cortex, the amygdala and other regions responsible for control of the amygdala and the hypothalamus generally.

The possible presence of neurological abnormalities, including varieties of epilepsy, found in prisoners incarcerated for violent behaviour (Bogerts 2017) raises the question of whether psychiatric assessment of mental health patients should include EEG (Gedye 1989) and MRI brain scan assessment (Schiltz 2013). Pathology that may be correctable includes removable tumours in the frontal lobe or in the hypothalamus (Malamud 1967). This raises ethical questions of legal culpability for antisocial or criminal behaviour.

Can the tendency for aggression be controlled? Learned control of aggression, after the developmental period, via a conditioning process to alter cortical influence on the hypothalamus, is somewhat problematic. Individuals seem to have an innate, genetically determined variability in emotional control (Baker 2008). Some neuroplasticity is required in the pre-frontal cortex for change in behaviour to occur but this seems to decline with brain maturation (Booij 2015).

Reduction of aggression by cognitive behaviour therapy has some supportive evidence. Motivated subjects using appropriate professional practitioners are required for change to occur. There is little support however for so called “anger management” in a group setting often directed by a variety of different practitioners with non professional backgrounds (Siegel 2009).

Conclusion

A great deal of information has recently been gleaned about the neurocircuitry controlling aggression in mammals, including humans. It is clear that both genes (Barr 2014) and life experience guide the development of these neural circuits differently in every individual (Craig 2009, Baker 2008, and Pavlov 2012).

There are also gender differences involving hormonal influences (Book 2001) as well as the particular differential development of the human prefrontal cortex. The latter does not mature until the mid 20s in males compared to the late teens in females.

Human aggression mirrors animal behaviour with classification into two types (Meloy 1988). Sudden defensive rage reaction is usually an impulsive threat response with marked sympathetic output, which does not involve the cortex. This can be compared to planned predatory attack behaviour requiring complex cortical involvement that takes place over a variable time period with little in the way of outward sympathetic signs.

The major risk factors that predict violent behaviour are youth, male sex, and substance abuse. There is little doubt about the evidence for the connection between substance abuse and violence. Alcohol, cocaine and methamphetamines impair the neural circuitry in the brain for control of aggression (Negus 2014).

Control of aggression may be somewhat altered by appropriate learning activities, cognitive behaviour therapy and conditioning which engages the pre-frontal cortex (Anderson 2018).

Ultimately it is hoped that these studies may lead to reduction of violent behaviour by modifying or regulating neural circuits of aggression. This could be by behaviour therapies, medication, and precision neurosurgery with deep brain stimulation using depth electrode placement for modulation of neuronal pathways.

Recently introduced non invasive transcranial magnetic stimulation also offers some promise for future treatment (Fields 2019).

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