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Biological correlates of psychopathy: A brief review

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Abstract

Purpose – The aim of this paper is to present and provide a critical review of most recent studies inquiring into brain abnormalities in psychopathy.

Design/methodology/approach – The authors provide an overview of the findings of neurobiological studies conducted in the last five years. Publications chosen for review were found using Web of Science, PsycINFO and Scopus search engines.

Findings – Data in the literature reveal that psychopathy is associated with brain abnormalities in frontal and temporo-limbic regions, i.e. regions responsible for moral decision making, emotional processing and learning. Additionally, interactions between the brain areas have been identified as crucial for the development of psychopathic personality traits. Research findings suggest that the flow of impulses between the frontal cortex and temporo-limbic structures in psychopaths is significantly hindered.

Originality/value – The current paper provides an in-depth review of most recent neurobiological studies inquiring into brain abnormalities associated with psychopathic personality traits. Moreover, a particular attention has been paid to identifying abnormalities in brain structures not previously studied in relation to psychopathy (e.g. mirror neuron system, white matter connections).

Keywords: psychopathy, neurobiological studies, brain abnormalities, frontal cortex, temporo-limbic areas, interhemispheric interactions

INTRODUCTION

Psychopathy is a clinical construct characterised by a constellation of interpersonal (e.g., deceitfulness, superficial charm, grandiosity), affective (e.g., lack of empathy, remorse, or guilt), lifestyle (e.g. impulsivity, irresponsibility), and behavioural (e.g., social deviance, criminality) features (Hare and Neumann, 2008). The most prominent and widely-used psychopathy measure has been the Hare Psychopathy Checklist (PCL; Hare, 1980), and its updated version – the Psychopathy Checklist-Revised (PCL-R; Hare, 1991), which consists of two factors. Factor 1 (Interpersonal/Affective) incorporates items such as superficial charm, lack of remorse and lack of empathy. Factor 2 (Lifestyle/Antisocial) clusters items measuring antisocial behaviour, impulsivity, irresponsibility and juvenile delinquency (Blair et al., 2005; Hare et al., 1990). PCL as well as PCL-R are strongly correlated with Cleckley's Clinical Profile (Cleckley, 1941), which suggests that they measure the same theoretical concept.

Psychopathic features appear to be genetically influenced, begin to manifest in childhood, and are relatively stable over time (Viding et al., 2007). Psychopathy is often referred to as the oldest mental disorder (Buzina, 2012). The concept of psychopathy has aroused increasing interest in many researchers, practitioners and theorists for centuries, however, the lack of agreement on what constitutes psychopathy as well as how to diagnose it has resulted in an ambiguous construct (Ogloff, 2006).

Much still remains unknown about the nature of psychopathy as a clinical construct. Specifically insufficient understanding exists regarding the origins of psychopathy, the role of environmental influences on the expression the disorder, and the underlying biological basis. Establishing the biological roots of psychopathy is a highly important endeavour given that such discoveries would likely have significant implications in better understanding the aetiology of psychopathy as well as potentially leading to the development of new treatments.

Psychopaths are characterised by severely disturbed personality patterns, with a deep lack of empathy (Hare, 1991) and increased levels of aggression, both reactive and instrumental (Blair, 2007). Key to research in the field is that psychopathy has been found to have a basis in brain function and brain structure (Hare and Neumann, 2008). Brain regions associated with the development of psychopathic features include the frontal lobe and the temporo-limbic areas.

The two major theoretical models of psychopathy have biological underpinnings. The somatic marker hypothesis (see Damasio, 1994 for a full review) states that when an individual makes a decision deficits in the ventromedial prefrontal cortex (vmPFC) lead to an individual being insensitive to negative consequences ensuing from their choices. In this way, their decision-making processes are not mediated by emotional responses. Support for the theory can be found from studying patients with lesions of the vmPFC. Patients with bilateral damage to the vmPFC have been well documented to develop severe impairments in personal and social-decision making and are subsequently unable to learn from previous mistakes as reflected by repeated engagement in decisions that lead to negative consequences (Bechara and Damasio, 2005).

The violence inhibition mechanism (VIM) model (see Blair, 1995 for a full review) explicates how aggression is controlled in some species of social animals. The theoretical basis for the model have been drawn from ethologists, Eibl-Eibesfeldt (1970) and Lorenz (1966), who proposed that an attack stops once one of the conflict participants displays submission cues. In humans, Blair (1995) noted, such cues include sad facial expression or tears. Importantly, the mechanism is necessary for moral emotions such as sympathy, empathy, remorse and guilt to develop. The absence of a VIM therefore is synonymous with the absence of moral emotions that inhibit aggressive behaviours. This hypothesis has been supported by research which found that empathy reduces aggression and leads to pro-social behaviours and altruism, which in turn, strengthens the social bonds and integrates societies (Decety and Lamm, 2006). The lack of appropriate VIM has been attributed to psychological deficits or adverse socialisation experiences (Blair, 2001). The amygdala is associated in the response to these stimuli (Blair, 2007). Amygdala dysfunction has an impact on only the affective component of empathy, leaving cognitive flexibility intact. Hence, individuals suffering from psychopathy are good at recognising others' emotions but, due to the lack of affective engagement, do not feel for others the way individuals with undisturbed amygdala functions do (Blair, 2001). Hare (1993) reported that psychopaths are capable of successfully completing theory-of-mind tasks. Theory of mind refers to the ability to "reflect on the contents of one's own and other's minds" (Baron-Cohen, 2001, p. 174).

Research into biological correlates of psychopathy is still in its infancy. Studies revealed the frontal cortex and temporo-limbic areas to be the key brain regions responsible for the development of psychopathic traits and behaviours, however, contradictory results have been reported. The purpose of this article is to review, summarise, and critically engage

with the findings of research into biological underpinnings of psychopathy. The reason for conducting an updated review was to achieve more information about the most recent research findings in the field.

(Please insert Figure 1 about here)

METHODOLOGY

A search in the Web of Science, PsycINFO and Scopus was performed in September 2013. The following keywords were used: *biological correlates of psychopathy, biology and psychopathy, brain abnormalities and psychopathy, neurobiological studies and psychopathy*. Date of publication served as the first selection criterion. Only papers published in the last five years were chosen. The abstracts of 33 studies were inspected in order to ascertain whether they contained relevant information. Finally, 20 relevant empirical studies were identified. In order to increase the clarity of this review, the research findings were grouped and presented in three main sections: the frontal cortex, the temporo-limbic areas, and interhemispheric interactions. This literature review was not conducted systematically in line with Cochrane methodology (Higgins & Green, 2011) but was intended to give an overview of the available material.

RESULTS

The frontal cortex

The frontal cortex is crucial for cognitive processes such as decision-making, problem solving or predicting future consequences (Rosenzweig et al., 1999). Importantly, it was suggested that damage to the frontal cortex may result in psychopathy, specifically damage to the prefrontal cortex (Kiehl, 2006). The dorsolateral prefrontal cortex plays an important role in the regulation of emotion and behaviour, and it has been suggested that this regulatory system is dysfunctional in psychopaths (Hoppenbrouwers et al., 2013). Among the less often investigated brain areas embedded in the frontal cortex which may also impact the development of psychopathic traits is the premotor cortex, specifically the mirror neuron system which is strongly connected with the ability to empathise (Fecteau et al., 2008).

The case of Phineas Gage is the first known and widely cited instance of the effect of the frontal cortex damage on human conduct (Weber et al., 2008). In 1848, Gage, a railroad foreman, experienced an incident in which an iron bar drove through his brain, damaging the prefrontal cortex. At first it seemed that the only long-term effects Gage would suffer from would be blindness in the left eye and left facial weakness. Nevertheless, further observations of Gage's demeanour brought new interesting insights into his condition. Specifically, the man, described as kind and even-tempered before the accident, became acting erratically, lost all restraints and showed no respect for others (O'Driscoll & Leach, 1998). This turned out to be a turning point which directed researchers' attention at the strong connection between mind and brain. Moreover, Lewis et al. (1986) conducted clinical evaluations of 15 prisoners sentenced to death (13 men and 2 women). The authors established that all prisoners suffered from a head injury, five had serious neurological problems (e.g. seizures, cortical atrophy), and seven had milder neurological impairments (e.g. history of blackouts, severe headaches). These findings support the supposition that particularly violent offenders suffer from neurological deficits (Cunningham and Vigen, 2002).

Neuroimaging studies with the use of magnetic resonance imaging (MRI) as well as functional MRI (fMRI) have provided new insights into structural abnormalities in individuals with psychopathy. Harenski et al. (2010) investigated the topic of moral decision-making in psychopathy. In order to address the issue from neurobiological perspective, they conducted an fMRI study in which the hemodynamic activity of imprisoned psychopathic and non-psychopathic offenders was recorded. Similar studies measuring prefrontal cortex activity have been conducted with healthy participants (Greene and Haidt, 2002; Moll et al., 2005), however, the problem of psychopathy in relation to moral decision-making has been largely neglected.

The prefrontal cortex

Harenski et al. (2010) recruited 72 adult male participants. Exclusion criteria included IQ below 80, head injury, history of psychotic disorder as well as current substance abuse. Notably, all but one of the subjects met the diagnostic criteria for past substance use disorder. Participants' psychopathy was measured with the use of PCL-R. All subjects who scored more than 30 were classed as psychopaths, whereas those who scored 29 or less – as healthy controls. Further, participants' brain activity was scanned while they viewed a series of different photographs. They were asked to judge whether the photographs shown to them

depicted acts of moral violation or not. The results reveal that non-psychopaths showed greater activation in the vmPFC when viewing pictures representing moral dilemmas. This trend was absent when psychopaths were scanned, and their brain activity remained similar across different conditions.

Harenski et al. (2010) found evidence to support the importance of the vmPFC for emotional processing and moral decision-making and thus in identifying psychopathic individuals. In a study involving 72 adult males, vmPFC activity was compared in psychopaths and non-psychopaths when shown photographs depicting acts of moral violation. Results indicated that psychopaths exhibited significantly lower levels of vmPFC activity compared to healthy controls. Dysfunctional vmPFC has also been associated with reactive aggression (Blair, 2010; Blair et al., 2005) as well as insensitivity to both positive and negative future consequences (Bechara et al., 2000). In addition, abnormal responses in the vmPFC have been found in children with psychopathic traits (Finger et al., 2008). Due to the sample selection of Harenski et al.'s (2010) the conclusions must be treated with caution. All subjects were recruited from a medium-security prison, and both psychopaths and controls had a history of past substance abuse. While this allowed for more reliable comparisons between the two groups it did introduce the confounding variable of neural deficits as a result of substance abuse.

Gray matter (GM) in the prefrontal regions

Yang et al. (2005) suggested that psychopaths do not constitute a homogenous group. They proposed a curious distinction between unsuccessful (i.e. individuals with criminal convictions) and successful (i.e. individuals whose crimes were not detected) psychopaths. Dissimilarities between the two groups were hypothesised to originate from differences in brain structures. Yang et al.'s research findings indicated that unsuccessful psychopaths had significantly reduced GM volume in the prefrontal cortex as compared to successful psychopaths. In a later study Yang et al. (2010) examined the prefrontal cortex of psychopaths in order to determine how its functioning affects participants' ability to avoid criminal charges. The research sample consisted of 16 unsuccessful psychopaths, 10 successful psychopaths and 27 controls. Their findings suggested that unsuccessful psychopaths, in comparison with controls, had statistically significant GM volume reductions in the right middle frontal cortex (MFC), right and left orbitofrontal cortex (OFC), and in the right rectal gyrus (RG). When compared with successful psychopaths, they exhibited

significant volume reductions in the right MFC as well as both right and left OFC. In addition, unsuccessful psychopaths showed cortical thinning in the MFC and OFC. These findings may explain why some psychopaths manage to avoid being caught when engaging in law-breaking behaviour. The poor judgement and decision-making of unsuccessful psychopaths may be linked to structural deficits in the MFC and OFC. Further, the results of MRI scans of successful psychopaths suggest that “relatively intact prefrontal volume may function as a protective factor that preserves the ability to either express psychopathic personality tendencies in more adaptive ways or conceal crimes more effectively to avoid arrest and/or convictions” (Yang et al., 2010, p. 552).

The MFC has been demonstrated to be crucial for error processing (Gehring and Fencsik, 2001). Furthermore, it has been shown that damage to the OFC may result in psychopathic behaviour. Patients with OFC lesions rarely reveal the signs of instrumental aggression, which constitutes one of the key attributes of psychopathy. Moreover, OFC lesions are usually connected with the dysfunctional affective and lifestyle factors of psychopathy (Kiehl, 2006). Importantly, Yang et al.’s (2010) findings indicated that certain brain deficits deemed responsible for “creating” psychopaths are not enough to construe the pathology. Instead, abnormalities listed by the researchers successfully elucidate the origins of antisocial behaviour, impulsivity, and poor decision-making. Accordingly, other brain structures and connections between them need to be examined in order to help further understand the phenomenon of psychopathic personalities (Weber et al. 2008).

Gregory et al. (2012) sought to investigate the association between GM volume and psychopathy in a study that examined differences between a group of 17 violent offenders diagnosed with both antisocial personality disorder and psychopathy (ASPD+P) and a group of 27 violent offenders suffering only from antisocial personality disorder (ASPD-P). For comparison purposes, 22 healthy non-offenders were also included in the sample, and the study design controlled for substance use disorders. The researchers were interested to discover whether the development of callous and unemotional traits stems from structural GM differences. The results revealed a significant reduction in GM volume in the bilateral anterior rostral medial prefrontal cortex (arMPFC) (Brodmann area [BA] 10); an area crucial for assessing social stimuli with the use of stored information as well as self-reflection, in psychopathic offenders but not in antisocial offenders without psychopathy. The GM volume of offenders with ASPD-P did not differ significantly from that of the control group of non-

offenders. These results suggest that different neurological deficits are associated with the callous affect and antisocial behaviour facets of psychopathy.

The premotor cortex

Empathy is a crucial concept when it comes to diagnosing psychopathy (Fecteau et al., 2008). Empathy is often described as a complex process or construct that involves both cognitive and affective components and is influenced by attitudes, context, and values (Gibbons, 2011). Empathy develops in children around the 2nd year of life, and importantly, empathy is a subjective process as it involves the affective experience and understanding of another's inferred emotional state (Decety and Jackson, 2004). The theory of embodied cognition or embodied simulation has been confirmed by the discovery of mirror neurons. Significantly, mirror neurons enable humans to share feelings, intentions, and actions of others and therefore are especially important for an individual's social development.

Fecteau et al. (2008) investigated whether dysfunctionality in the mirror neuron system (MNS) is likely to effect an individual's empathic reactions. Their interest concentrated around the perception of pain occurring in others. Reactions in the MNS were evaluated against psychopathic personality traits. Psychopathy was assessed with the use of the Psychopathic Personality Inventory (PPI) (Lilienfeld, 1990), which is a self-report measure designed for subclinical samples (the PPI had been found to correlate with the PCL-R). The sample for this study included 18 male, right-handed college students. Fecteau et al. (2008) found a negative association between the motor evoked potentials (MEP) amplitude and the cold-heartedness subscale of the PPI. This supports the theory that the MNS is closely linked with the emotional dimension of psychopathy. A similar study conducted by Avenanti et al. (2005) revealed that participants who gave higher scores on the intensity of pain observed in others, also displayed greater modulation of motor cortex excitability. It can be inferred, therefore, that the observer's MNS is essential for learning social reactions to pain.

The temporo-limbic areas

The temporo-limbic area has been reported to play an important role in emotional processing and learning (Rosenzweig et al., 1999). The main temporo-limbic structures examined in relation with psychopathic traits include the amygdala and the hippocampus. Recent studies in the field significantly widen the scope of research and other temporo-limbic areas have

also been found to be implicated in the expression of psychopathic personalities (see Meffert et al., 2013).

The hippocampus

Boccardi et al. (2010) examined the hippocampal shape and volume of psychopathic and non-psychopathic individuals. None of the participants suffered from psychosis, had cluster A personality disorder, or brain damage. However, all participants met the diagnostic criteria for alcohol abuse with early onset and 77% of the sample met criteria for polysubstance dependence. It should be noted, however, that these individuals had no access to alcohol for at least three months and no access to illicit drugs for at least one week prior to the MRI examination. Moreover, although healthy controls were matched for age and gender with the experimental group, they had no history of mental disorders or substance abuse.

Boccardi et al. (2010) found no differences in hippocampal volumes between experimental and control groups. Previous studies yielded similar results (e.g. Barkataki et al., 2006). Contrastingly, Laakso et al. (2001) found a negative correlation between PCL-R scores and posterior hippocampal volume. Boccardi et al. (2010) did however discover differences in hippocampal shape among the different groups. Specifically the high psychopathy group, in comparison with the medium psychopathy and control groups, “had a significant depression along the longitudinal hippocampal axis” (p. 439). Importantly, the depression may indicate less tissue in the dentate gyrus, where CA4 region is located. The neurons in CA4 regions are thought to play a role in the expression of emotions. Further, Boccardi et al. (2010) suggested that both the high and medium psychopathy groups had abnormal enlargement of the lateral borders in both the right and left hippocampi compared to controls, throughout CA1, CA2-3 and the subicular regions. The CA3 region is thought to be associated with the processing of emotional information. According to the researchers, abnormalities in different hippocampal regions, especially the ones responsible for emotional processing, effect the development of psychopathic traits. The hippocampus may play an important role in fear conditioning and impulsivity (Cardinal, 2006). Additionally, Boccardi et al.’s (2010) research demonstrated how brain structure abnormalities may differentiate the severity of psychopathy.

The amygdala

In Yang et al.'s (2010) study examining brain deficits in successful and unsuccessful psychopaths, it was discovered that unsuccessful psychopaths showed a significant hippocampal asymmetry (right hippocampus larger than the left), whereas successful psychopaths showed no such defect. Yang et al. (2009) found bilateral amygdala volume reductions in individuals with psychopathic personalities, and these reductions were found to be positively correlated with total as well as facet psychopathy scores. Yang et al. (2010) observed significant volume reductions in the left (26%) and right (20%) amygdala in unsuccessful psychopaths, but not in controls. In addition, successful psychopaths exhibited volumetric reductions in the amygdala (9.3% in the left and 12.7% in the right). Bilateral amygdala volume reductions may be responsible for arrested moral development - a factor potentially leading to re-offending.

Dolan and Fullam (2009) discovered reduced amygdala responses to fearful faces in patients with schizophrenia and psychopathic personality traits. Similarly, Harenski et al.'s (2010) study also utilized visual stimuli. Therefore, the results do not provide an unequivocal evidence for the amygdala's role in moral decision-making. However, Glenn et al.'s (2009) study, where moral dilemmas rather than pictures of moral violations were presented, found that psychopathy is positively correlated with reduced amygdala activity. Glenn et al. (2009) proposed that reduced amygdala functioning in psychopaths reduces the feeling of guilt or remorse.

Kiehl (2006) proposed that the removal of the anterior temporal cortex in humans may lead to the alleviation of psychopathic symptoms. This may suggest that anterior temporal cortex dysfunction, rather than its absence, results in the expression of psychopathy. The reduction of psychopathic symptoms was also observed in patients who underwent amygdalotomies, whereas patients with temporal lobe epilepsy often exhibit psychopathic features (Blumer, 1975).

Marsh et al. (2013) conducted an fMRI study investigating empathic responsiveness in the amygdala in youths with psychopathic traits. The research sample included 37 participants (15 male and 22 female) with Oppositional Defiant Disorder or Conduct Disorder, and psychopathic traits as measured with the Psychopathy Checklist – Youth Version (PCL:YV) (Forth et al., 2003). The control group consisted of 20 subjects. The results revealed that youths with psychopathy showed reduced activity in the rostral anterior

cingulate cortex, ventral striatum (putamen) and amygdala. The reduced amygdala activity was most profound when the pain was imagined as occurring to someone else. Additionally, it was found that the higher the psychopathy scores, the less the empathic responses. In direct contrast, Decety et al. (2009) showed increased amygdala and ventral striatum activity in response to viewing pictures of others' pain in youths diagnosed with Conduct Disorder. This may imply that it is the emotional rather than behavioural component of psychopathy that is linked with dysfunctional amygdala activity.

Anterior cingulate cortex (ACC)

Research has shown that different brain regions are activated when watching painful situations from self- or other- perspective. An fMRI experiment by Jackson et al. (2006) revealed brain regions that were involved when subjects were asked to imagine a painful situation from a self- and other-perspective. The overlapping areas (regions activated with similar strength in both conditions) were the parietal operculum, ACC (BA32) and the anterior insula. Some significant differences were also observed. For example, pain visualisation from self-perspective yielded greater activation of the secondary somatosensory cortex, the ACC (BA 24a'/24b') and the insula proper. In the other-perspective condition more activity was recorded in the right temporo-parietal region – a brain region central in perspective-taking, self-identification and the sense of agency.

Basoglu et al. (2008) conducted a magnetic resonance spectroscopy (MRS) study of psychopathy among military conscripts in Turkey. Basoglu et al. (2008) revealed the importance of the anterior cingulate cortex (ACC), located in the limbic lobe, as well as two acids, N-acetyl aspartate (NAA) and creatine (Cr), for the emergence of psychopathy. Namely, lower ACC NAA/Cr ratio has been associated with higher PCL-R total scores as well as PCL-R Factor 1 (interpersonal/affective) scores. The findings suggested that “the neural integrity of the ACC might be related to severity of psychopathy” (p. 77).

The ACC had been recognised as crucial in accounting for the biological causes of certain psychopathic personality traits in a number of studies. The ACC is a large brain area which may be anatomically subdivided into two components: rostral and caudal. The rostral region is often termed the “affective” component of the ACC, as it is responsible for emotional regulation and pain perception. The caudal or “cognitive” division, on the other hand, is connected with the prefrontal cortex and hence plays an important role in some executive functions such as task switching or error monitoring (Kiehl, 2006). Lesions in the

ACC may lead to emotional unconcern, hostility, erratic behaviour, difficulties in error monitoring as well as disturbed affective facial processing; many of the most prominent features of psychopathy (Kiehl, 2006; Mesulam, 2000; Swick and Jovanovic, 2002). Additionally, Kiehl et al. (2004), using a lexical decision task, demonstrated impaired functioning of the ACC in criminal psychopaths. Decreased ACC activation in psychopaths, when looking at pictures with emotional content was also reported by Müller et al. (2003).

GM in temporal regions

Gregory et al.'s (2012) study aimed to investigate whether any GM volume differences between individuals with ASPD and psychopathy (ASPD+P), and individuals with ASPD without psychopathy (ASPD-P), as well as healthy controls, existed. The analysis of brain scans revealed significant GM volume reduction in the arMPFC of psychopaths. Gregory et al. (2012) did not limit their interest to the frontal lobe structures. Assessment of temporal lobe areas revealed that psychopaths, in comparison with participants with ASPD-P, showed significant reductions of GM volume in the bilateral temporal poles, specifically extended from lateral temporal pole regions (BA 38) into the inferior temporal gyrus (BA 20); these areas are responsible for storing contextual knowledge which enables emotional evaluation of social stimuli.

Temporal lobe atrophy has been discovered in individuals with such conditions as frontotemporal dementia or Kluver-Bucy syndrome. Bilateral temporal lesions lead to cognitive, emotional as well as behavioural deficits (Gościński et al., 1997). Clinical features of the frontotemporal dementia include loss of social awareness, disinhibition (e.g. violent behaviour, promiscuousness), emotional indifference and lack of empathy (Lough et al., 2006). Similarly, Kluver-Bucy syndrome, a rare human pathology, affects the sufferer's emotional functioning in that they become emotionally unconcerned and empathically uninvolved with others (Gościński et al., 1997). Gregory and colleagues (2012), therefore, reveal some interesting neurological overlaps between psychopathy and other brain disorders.

Interhemispheric interactions

Research reveals that brain regions should not be examined in isolation because complex interhemispheric interactions may be responsible for the development of certain psychopathic traits. Dysfunctional connections between the frontal lobe and temporo-limbic areas were discovered to play a crucial role in the emergence of psychopathy.

Prefrontal cortex and subcortical regions

Cognitive and emotional processes permeate each other and have a significant influence on human behaviour (Gray, 2001). Studies assessing brain activity have revealed that an emotion-cognition interaction is especially prominent in the prefrontal cortex (Gray et al., 2002). Indeed, psychopathy is often described as a disorder of executive as well as affective functions and this emotion-cognition interaction may be of special importance for developing of a better appreciation of the condition.

Müller et al. (2008) investigated emotional and cognitive deficits in psychopathy within a sample of 10 criminal psychopaths recruited from a forensic psychiatric facility along with a control groups of 12 healthy male non-offenders. All participants were required to complete two tasks; one affective and one cognitive. As hypothesised, the fMRI data revealed differences in emotion related task performance as well as in brain activation pattern between psychopaths and non-psychopaths. For the cognitive task, non-psychopaths made more errors under a negative emotion condition than in the positive or neutral conditions. This finding is consistent with previous research that suggests negative emotions drain more energy that cannot therefore be used for more complicated cognitive processes (Ellis et al., 1984). The same regularity was not observed among psychopaths.

Müller et al. (2008) predicted that emotion-cognition interaction requires the involvement of both frontal and temporal areas. Indeed, interaction between the regions was recorded for non-psychopaths, but not for psychopaths. Furthermore, non-psychopathic individuals showed more activation in the prefrontal cortex as well as the right superior temporal gyrus as compared to psychopathic individuals. The regions responsible for emotion-cognition integration were not activated in psychopaths. Müller et al.'s (2008) results suggest that both frontal and temporal lobes were pivotal for the emergence of psychopathic personality traits.

Hoppenbrouwers et al. (2013) proposed that deficits in the dorsolateral prefrontal cortex (DLPFC) prevented psychopaths from regulating emotional behaviour however they suggest that these deficits alone cannot explain psychopathic behaviour. Coccaro et al. (2011) proposed that the DLPFC controls subcortical regions (e.g. the amygdala) and that these regions are involved with the expression of emotional impulses. These deficits may be responsible for the inability of psychopaths to learn socially appropriate responses to emotions. However, Meffert et al. (2013) suggested that psychopaths are able to empathise

with others but it is not a spontaneous response. In the case of psychopaths, they would express empathy when it did not interfere with goal-directed behaviour. The plethora of research associating psychopathic traits with frontal cortex deficits may well be evidence to support Meffert et al.'s (2013) finding that among psychopaths the emotional regulator system is dysfunctional, and this consequently allow psychopaths to express emotion only when it is of benefit to them.

White matter connections

Craig et al. (2009) sought to investigate the white matter connections, such as the uncinate fasciculus (UF), between the amygdala and orbitofrontal cortex (OFC) using diffusion tensor imaging (DTI). This shift of focus reflects most recent discoveries that it is the dysfunctional communication between frontal and temporal structures that may significantly contribute to the development of psychopathy. Interactions between the amygdala and prefrontal cortex are deemed to be responsible for emotion regulation as well as stimulus-reinforcement associations (Davidson et al., 2000). Craig et al.'s (2009) sample consisted of 18 adult male volunteers, nine of whom had PCL-R scores of 25 or higher (mean = 28.4). Participants did not take any medications at the time of the study and no other mental or neurological disorders were detected.

Craig et al. (2009) found that psychopaths, compared with healthy controls, had significantly reduced fractional anisotropy (FA) (i.e. myelination) in the right UF. Additionally, UF anatomical abnormalities were connected with antisocial behaviour. Overall, these results indicate a strong correlation between UF malfunctions and social deviance as well as emotional detachment. Furthermore, similar UF abnormalities were found in post-mortem studies of patients with schizophrenia who exhibited violent and aggressive behaviour (Highley et al., 2002). Craig et al.'s (2009) findings indicated that the limbic amygdala-OFC network might play a role in antisocial behaviours. Specifically, the reported UF abnormalities hinder the integrated functioning of the amygdala and OFC that may result in decisions being made without the emotional processing of available information.

Craig et al.'s (2009) results suggested a new direction in neurobiological research investigating psychopathy. Recently, Motzkin et al. (2011) examined the structure and activity of UF with the use of DTI as well as fMRI. Adult male inmates from a medium-security prison in Wisconsin were recruited for the study. Similarly to the findings of Craig and colleagues, Motzkin et al. discovered lower FA values in the right UF among

psychopathic individuals. Psychopaths, in comparison to control participants, displayed a reduction of white matter integrity in the right UF. The fMRI study revealed psychopaths had a reduced functional connectivity between the ventromedial prefrontal cortex (vmPFC) and amygdala as well as between vmPFC and right precuneus/PCC.

DISCUSSION

A detailed review of the literature has suggested that there is strong evidence that brain abnormalities are associated with the expression of psychopathic traits and behaviours. Two major areas of interest by researchers are the frontal cortex (i.e. Greene & Haidt, 2002; Moll, et al., 2005; Yang et al., 2010; Hoppenbrouwers, et al., 2013; Meffert et al., 2013) and the temporo-limbic areas (i.e. Barkataki, et al., 2006; Laakso, et al., 2001; Boccardi et al., 2010; Yang et al., 2010 Hoppenbrouwers, et al., 2013; Meffert et al., 2013).

Research indicates that damage to the frontal cortex may result in psychopathic behaviour (Kiehl, 2006). The somatic marker hypothesis put forward by Damasio (1994) holds that abnormalities in the vmPFC can lead to insensitivity to negative consequences of one's choices. Indeed, Harenski et al. (2010) discovered greater activation in this prefrontal cortex region in healthy participants but not among psychopaths. Such a finding supports the importance of the vmPFC for moral decision making and emotional processing. Previous studies associated dysfunction in this brain area with reactive aggression (Blair, 2010; Blair et al., 2005). In addition, research revealed that a dysfunctional mirror neuron system is closely linked with the emotional dimension of psychopathy (Fecteau et al., 2008).

Temporo-limbic areas participate in emotional processing and learning (Rosenzweig et al., 1999) and therefore it comes as no surprise that abnormalities in this brain area are associated with psychopathy. Abnormal amygdala activity (Glenn et al., 2009; Harenski et al., 2010; Marsh et al., 2013) and volume reductions (Yang et al., 2009; Yang et al., 2010) have been identified among psychopathic individuals. Reduced neurochemical activity in the ACC has also been discovered to be associated with increased levels of psychopathic traits (Basoglu et al., 2008; Marsh et al., 2013). Kiehl (2006) reported that disturbances within the ACC were found to be connected with emotional blunting, hostility or erratic behaviour. With regards to the role of the hippocampus in predicting psychopathy research findings have been inconsistent. Boccardi et al. (2010) discovered no abnormalities in hippocampal volumes in psychopaths, whereas Laakso et al. (2001) found that reductions in the posterior hippocampal volume were associated with greater levels of psychopathy.

While all of these findings are strongly suggestive that deficits in the frontal and temporo-limbic regions are directly implicated in the occurrence of psychopathy, Hoppenbrouwers et al. (2013) demonstrate that these regions alone are insufficient to provide a comprehensive neurological explanation for psychopathic behaviour. Abnormalities have been found in other brain structures such as grey matter volume (Gregory et al., 2012) and white matter connections (Craig et al., 2009). Müller et al. (2008) implied that a free flow of impulses between the frontal cortex as well as temporo-limbic areas in psychopaths is significantly hindered. Additionally, deficits in prefrontal and subcortical regions of the brain may have an adverse effect on the expression of emotional impulses (Coccaro et al., 2011).

The two major models of psychopathy, the somatic marker hypothesis (Damasio, 1994) and the violence inhibition mechanism model (Blair, 1995) are based on the premise that individuals with psychopathy are unable to associate antisocial behaviour with negative affect that are normally elicited by distress observed in others and that psychopathic individuals are therefore unable to process information such as distress cues which are not central to their own objectives. The majority of the research tends to suggest that this is a result of disrupted neural communication or structural abnormalities in the brain.

However, as both Cleckley (1941) and Hare (2003) considered psychopathic individuals to have superficial charm as a trait, this does not support the theory that individuals with psychopathy are unable to associate antisocial behaviour with negative affect that are normally elicited by distress observed in others. It would appear as Meffert et al. (2013) proposed, that psychopathic individuals can select an emotional response that is congruent to their current goals and in certain social situations this would include the expression of empathy. Future research should therefore investigate the ability of psychopathic individuals to regulate empathy, and if identified the potentiality to regulate other emotions, along with identifying the neurological systems that regulate this ability.

Moreover, Boccardi et al. (2010), Fectau et al. (2008), Gregory et al. (2012), and Yang et al.'s (2010) findings lend credence to the supposition that psychopaths do not form a homogenous group. Different dimensions of psychopathy have been linked with dysfunction in distinct brain regions. For example, Gregory et al. (2012) found that only the brain function of individuals with both ASPD and psychopathy deviates from the norm, which is in line with Karpman's (1951) assumption that primary psychopaths, characterised by more psychopathic traits, are born, whereas secondary psychopaths, who display more antisocial

behaviours, are created through environmental factors. Nevertheless, as demonstrated in this review, most studies into brain abnormalities related to psychopathy fail to control for psychopathy variants. Participants who meet the established total cut-off point are classed as psychopaths and the different dimensions of the disorder are not considered separately. Additionally, Yang et al. (2010) distinguished between successful and unsuccessful psychopaths but this classification does not directly correspond with the primary/secondary dichotomy. The lack of a uniform approach in this respect can have a significant effect on study findings and can result in contradictory evidence.

Another fundamental problem observed in the literature regarding the biological bases of psychopathy relates to the consistent use of small samples. The difficulty of finding individuals with psychopathic traits is understandable however larger samples ought to be used in order to avoid not only the occurrence of Type II errors but to increase the generalizability of research findings. Additionally, many studies are performed upon samples comprised of individuals with co-morbid diagnoses. The inclusion of participants different from one another in a way that is hidden from the researcher is a serious concern in *in vivo* studies because uncontrolled for differences may render comparisons between the treatment and control groups highly biased (Hanfelt, 1997). Indeed, it has been demonstrated that substance abuse can lead to brain abnormalities therefore results utilizing such samples are lacking in reliability. For instance, Sokolov et al. (2003) found significant gene alternations and temporal cortex abnormalities among individuals with a history of alcohol abuse or dependence. Moreover, a more standardised method of determining cut-off points for psychopathy diagnosis is recommended. For example, Cooke and Michie (1999) have suggested PCL-R cut-off scores of 30 for North American, and 25 for European participants. Such methodological differences across studies render comparisons between them difficult and highly problematic. Therefore, a more universal approach is needed to verify whether the obtained results are replicable.

Furthermore, most studies cited in this review employed MRI and fMRI techniques. In such studies cognitive processes are often inferred on the basis of the activation of a particular brain area, an approach referred to as 'reverse inference'. Such inferences are also used when activation in an unexpected brain region is detected. Poldrack (2006) explained that "this kind of 'reverse inference' is not deductively valid, but rather reflects the logical fallacy of affirming the consequent" (p. 60). Indeed, some studies demonstrated that a brain region activated during a task may be not required for the task (Poldrack, 2008). According to

Poldrack (2006), 'reverse inference' can prove useful when testing new hypotheses, however, the reliability of the technique depends on its success to expand the current understanding of the connections between the mind and the brain. Moreover, Judenhofer et al. (2008) suggested that synergising positron emission topography (PET), which is highly sensitive to tracking biomarkers in vivo, MRI, and fMRI would significantly increase the value of imaging studies.

Limitations

This review demonstrates that psychopathic traits and behaviours are reflected in brain dysfunction and structural abnormalities. However, the purpose of this review was to focus on most recent findings in the area of neurobiology and psychopathy and hence a non-systematic approach was adopted. Therefore, the article does not identify and appraise the key research evidence relevant to biological origins of psychopathy. Further, due to the brevity of this report, a systematic summary of most recent findings in the field could not be provided.

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