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Neuroimaging on Brain Structural and Functional Abnormality of Borderline Personality Disorder

Yuet Yung, Lau[1,a,*]

[1]*Department of Psychology, The Education University of Hong Kong, 10 Lo Ping Road, Tai Po, New Territories, Hong Kong, China*
a. s1138367@s.eduhk.hk
**corresponding author*

Abstract: This article is a comprehensive review of borderline personality disorder (BPD) based on the neuroimaging technique. The paper incorporated the etiology of BPD, the correlated brain structure and function abnormality of BPD found by neuroimaging techniques, influence of brain abnormality and recommendations for future research directions. The method used in the paper is to generalise results from pre-existing research and studies by reviewing the literature. The results and discussion section will focus on the comparison between BPD and non-BPD subjects, intending to highlight the most significant anatomical and functional abnormalities in the brain such as the hippocampus, the amygdala and the primary visual processing area. Furthermore, the impact of early trauma, and the connection between brain abnormalities and emotional dysregulation will be discussed in the paper. The suggestions and discussions section at the end will cover the current limitation of BPD neuroimaging research based on the selection bias on gender and provide directions for future research. The overall goal of the current study is to increase knowledge about BPD.

Keywords: borderline personality disorder, neuroimaging, early trauma, emotional dysregulation, gender

1. Introduction of Borderline Personality Disorder (BPD)

A form of personality disorder known as borderline personality disorder (BPD) is known to have a number of abnormalities in the structure and function of the brain. including the abnormal size of hippocampus-amygdala region and the appearance of emotional dysregulation behaviour. BPD is characterised by a high degree of impulsivity, repeated acts of self-harm, including suicidal behaviour, and affective instability brought on by a high degree of mood reactivity and inappropriate, extreme rage. Based on the Surveys done by Chapman and colleagues BPD is thought to be prevalent in the general population at 1.6% and in inpatient psychiatric patients at 20% [1]. The first study that connected BPD and brain dysfunction was published in 1980, and only recently have neuroimaging techniques been used to study BPD [2].

A popular neuroimaging method used nowadays in the study of psychology is magnetic resonance imaging (MRI). MRI will be utilised to examine anatomical abnormalities in the brain and to evaluate cognitive abilities [3]. Functional magnetic resonance imaging (fMRI), a different set of imaging methods, is used to display temporally and spatially varied changes in brain

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metabolism. Glover predicted that these metabolic changes might be brought on by either task-induced cognitive state changes or uncontrollable neural processes that occur under brain rest [4]. Presurgical planning, clinical psychiatry/psychology, and the cognitive neurosciences have all used fMRI many times.

The hippocampus and the amygdala are areas within the limbic system, a set of brain regions that are involved in processing emotion and memory. The hippocampus is responsible for controlling hostile behaviour such as aggressive and impulsive [5]. The motivational and affective processes of organisms depend heavily on the amygdala because it is the region responsible for receiving neural input from the brain that would ultimately encodes the internal states [6]. The amygdala and hippocampal volumes have drawn the most attention because preliminary research revealed that these structures might be impacted by exposure to emotional and physical trauma [7]. Research has revealed that stress or other environmental factors may have an impact during the earliest stages of development [5]. For example, an animal stress model results showed a connection between hippocampus volume loss and stress [8]. In other words, the connections between stressful events and the volume of hippocampus have attracted great attention. Particularly, in the study of BPD, a common characteristic of stress-related mental disorders is thought to be a loss in hippocampal and amygdala volume.

In short, this paper will concentrate heavily on the two types of neuroimaging techniques, namely MRI and fMRI because they are both frequently utilised for studying mental conditions. In addition, the current study aims to evaluate recent studies on the neuroanatomical variations seen between people with and without BPD to investigate the abnormalities in brain anatomy and function in BPD patients. In addition, the paper will explore the influence of early trauma and the relationship between brain abnormalities and behaviours.

2. Methodology

This paper reviews the research on BPD by analysing articles from PubMed, ScienceDirect and Research Gate. The publication date of the research and studies were not restricted in the study. However, relevant articles were found between 2000 and 2022. In total, 23 articles were selected. During the selection process, the following combinations of terms were used: “borderline personality disorder”, “MRI”, “fMRI”, “brain structure abnormality”, “childhood trauma experience”, “aggression” and “impulsivity”.

The major emphasis of research could be divided into four parts: (1) Using MRI, BPD group was found to have several brain structure differences compared to the non-BPD group, such as the hippocampus, amygdala and the primary visual cortex; (2) Using fMRI, BPD group found to have higher sensitivity and emotional reactions in response to external stimuli, particularly the negative emotion stimuli; (3) early traumatic experiences are found to associate with the development of BPD; (4) emotional dysregulation is correlated to the brain structural abnormalities.

3. Brain Structural Abnormality

The first published MRI-based study focusing on the atrophy of hippocampus in BPD patients can be traced back to Driessen and colleagues [9]. By comparing brain structures between BPD patients and non-BPD subjects, the study examined the associations between early traumatisation experience and structural changes within the brain of BPD patients. Driessen and colleagues hypothesised a negative correlation relationship existed between early childhood traumatic experience and brain structural abnormality in the hippocampus-amygdala region [9]. In addition, to investigate the hippocampus-amygdala changes, researchers also examined other regions of interest, including the temporal lobes and prosencephalon. The study recruited 21 female BPD patients in the experimental

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group and 21 comparative subjects with no previous psychiatric or psychotherapist experiences in the healthy controls group. Self-report measurement and neuroimaging techniques were used in the study. Aimed to detect and categorise various forms of childhood abuse and trauma, researchers used the Childhood Trauma Questionnaire (CTQ). Participants are required to rate a broad spectrum of problems on a Likert scale, including their mental, physiological, and sexual encounters with neglectful and abusive behaviour. The length of experience was also considered. Hence, the researchers were able to analyse the impact of traumatisation in terms of intensity and duration. For the neuroimaging techniques, MRI was applied to all the regions of interests. The researchers made several adjustments to match the research objectives. For instance, to guarantee that the entire hippocampus was covered, researchers delineated the region of the hippocampus by including the region of the superior colliculus and interpeduncular cistern.

The results of the MRI and questionnaire allowed the researchers to make several pronounced conclusions. Firstly, between the BPD group and the healthy controls, there was a notable difference in the mean hippocampus size. Driessen and colleagues discovered that the left and right hemispheres of the hippocampus had been significantly reduced in the BPD group by 15.7% and 15.8%, respectively [9]. Additionally, the left and right amygdala showed 7.9% and 7.5% decreases. Lastly, measurements for the prosencephalon and temporal lobes showed no difference. These findings proved that BPD patients' brains differ from those of non-BPD participants, even if not all regions of interest discovered differences in brain structure volume. In addition to the change in brain structure volume, researchers discovered that the BPD group also reported a higher stress-related experience, such as a longer duration of traumatisation. Using correlation analysis, it was discovered that the hypothetically negative correlations between early trauma and brain volume existed only in the overall sample and not in the sample from the separated group. In other words, no significant negative correlation was found in the BPD group alone. Despite the fact that Driessen and colleagues were unable to identify a significant negative correlation link in the separate group, the results of the entire sample may be used as evidence to support the negative correlation between traumatic experience and alterations in the brain volume in BPD [9]. Several studies that followed their investigation discovered comparable findings regarding brain volume in BPD patients [9].

Another MRI-based investigation with 10 female BPD patients and 23 healthy controls was carried out by Schmahl and colleagues [10]. The research discovered reductions in the left and right hippocampus by 11% and 16%, respectively, and the left and right amygdala by 23% and 21%, respectively. They found that when researchers took into account the whole brain volume, years of schooling, and age, the difference in hippocampus and amygdala volume between the BPD patients' group and the health controls group became more significant [10]. According to Irle and colleagues [11], structural MRI revealed that the right hippocampus area and parietal cortex of the BPD group (30 females) had significantly lower brain volumes, with decreases of 17% and 11%, respectively. Based on the result, Irle and colleagues concluded that a significant relationship between decreased hippocampus size and more severe clinical symptoms and neuropsychological abnormalities following trauma was found [11]. Nevertheless, the structural MRI results enabled the researcher to identify the associations between specific personality features in BPD participants and the parietal cortex. They found that compared to control group, BPD subjects' parietal brains displayed a noticeably stronger leftward asymmetry. More psychotic symptoms and schizoid personality traits were substantially linked with decreased leftward asymmetry in BPD patients.

As shown by the aforementioned research, the hippocampus, amygdala, and parietal region in particular are different in the brain structures of BPD participants compared to the non-BPD group. Meanwhile, the conclusion suggests that in addition to stress-related experience, other confounding factors should be considered to determine the abnormal brain condition in BPD. In short, MRI

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could be utilised to investigate the functional abnormality in the brain of BPD patients in addition to identifying abnormal brain structures.

4. fMRI - Brain Structural Abnormality

Networks involved in emotion processing in healthy subjects and those with impaired affect in schizophrenia participants have started to be revealed by neuroimaging studies. The neurological underpinnings of the emotional instability in BPD are still poorly understood. In an effort to establish a link between mood swings and the genetic underpinnings of BPD, Koenigsberg and colleagues used the blood-oxygen-level-dependent (BOLD) signal detected by fMRI to investigate the pattern of regional brain activation throughout analysing pleasant and unpleasant stimuli and attempted to conduct an investigation on the variations in brain activity between the BPD and healthy control groups [12]. In the study, both genders were represented, resulting in 17 healthy subjects and 19 BPD patients. The participants were required to view a sequence of emotionally charged images that evoked both positive and negative emotions. A total of 25 negative and 25 positive images were shown to each individual while fMRI scans were being taken. Several parts of the brain were activated when participants focused on the emotional picture. Self-report was also given to the individuals as a manipulation check in order to validate the fMRI results.

Researchers discovered various brain activity patterns in response to pleasant and unpleasant emotion images using the self-report and fMRI results under between-group comparison. Fundamentally, no difference was found in terms of the subjective valence and emotional arousal rating result. The outcome showed that there was no variation in the subjective perception of emotional intensity. Despite this, evidence indicated that BPD individuals had different levels of sensitivity and emotional activity. Researchers discovered a noticeable difference in BOLD activation inside the amygdala and primary visual processing area when they analysed the fMRI data based on the comparison between negative emotion images and rest state conditions in two groups. Using the example provided by Koenigsberg and colleagues, they postulated that facial recognition had been linked to amygdala activation, specifically in the left amygdala region [12]. To put it another way, amygdala activation is related to processing fearful or sad faces in real-world situations [12]. In accordance with the results of earlier research, the amygdala collaborates with the primary visual processing areas on facial expression identification while processing negative visual information because the amygdala projects visual information onto the visual cortex [12]. Based on this finding, one interpretation of research findings is that negative emotional stimuli would trigger greater activity in BPD's primary visual processing areas. The fMRI results verified the assumption. The amygdala region and primary visual processing cortex were more active in the BPD group. It is safe to say that this increased activity caused them to be more conscious of the emotional inputs that the non-BPD individuals appear to overlook. The data may help explain why BPD patients are more likely to notice facial emotional expressions. The discoveries might help researchers comprehend BPD's complicated and intensely emotional features. The characteristics of hyperactive amygdala in BPD are found in another study. Mier and colleagues are the first study to investigate the correlation between the neuronal activity and the theory of Mind [13]. Based on their explanation, the theory of mind refers to the awareness of one's own and other people's intentions, wishes, and desires.

The previous research, such as the above-mentioned study, found that processing negative visual stimuli resulted in amygdala hyperactivation. Based on the finding, Mier and colleagues continued to hypothesise that individuals with BPD have amygdala hyperactivation even at the first level of processing, which is the processing of neutral faces without the need to assign an emotional state [13]. In other words, the researcher intended to continue the investigation on understanding the functional differences between BPD patients and non-BPD individuals regarding emotional

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recognition and amygdala activity. The study recruited 13 BPD patients and 13 healthy control subjects. Participants were required to match a descriptive statement to a face stimulus. The descriptive statement contained three aspects of information, including the emotional intention, state and the psychical characteristics of a depicted person. The face stimuli were designed to be either a neutral expression or an expression embedded with emotional content such as joyfulness and anger. According to the fMRI results, there are two differences between the brain activity in BPD and the healthy controls. On the one hand, patients with BPD displayed increased levels of activation in 4 brain areas, including the left amygdala, somatosensory, primary motor cortex and the right visual association cortex. On the other hand, BPD patients displayed reduced levels of brain activity in 4 areas, including the right inferior, prefrontal gyrus, thalamus, the left visual association cortex and cerebellum. That is to say, the fMRI results confirmed the left amygdala activation. As a result, the data supported the hypothesis. The aforementioned research has demonstrated that BPD patients' increased brain activity, particularly their heightened amygdala activation, represented their propensity for negative feelings and intents as well as their sensitivity to emotional-related social-cognitive tasks.

5. Etiology of Traumatic Childhood Experience

According to the studies cited above, traumatic childhood experiences are one of the environmental elements that contribute to the development of BPD. In order to comprehend the connection between early trauma and the start of BPD, Bozzatello and colleagues utilised a biopsychosocial perspective and produced a number of clear conclusions [14]. They began by outlining the significance of the insecure model of attachment. According to the attachment theory, when an individual grows up in an environment with insufficient attentions, care and affection or if they report having been abused and neglected by caregivers, the ability to recognise, control, and tolerate emotional responses would be less likely to emerge in the later life [15].

Battle and colleagues reported that patients with personality disorders frequently report having been abused as children, in particular, BPD is more frequently linked to cases of child maltreatment and neglect [16]. Bozzatello and colleagues concluded that several types of abuse are most commonly reported by the BPD patients, including sexual abuse, physical and verbal abuse and bullying [14]. Each type of the abuse experience will lead BPD patients to engage in various unhealthy behaviour. For example, numerous researchers found a significant correlation between sexual violence and psychotic symptoms in young BPD patients [17]. Moreover, a more severe clinical presentation, including a strong sexual impulsivity, a larger number of suicidal attempts, and drug dependence, was associated with longer exposure to sexual assault [18]. In situations involving physical and verbal abuse, they have been linked to the experience of broken bones, choking, or receiving criticism and judgment from others. Moreover, the personality dimensions are affected by this abuse, including identity disturbance and affective dysregulation. These stressful social events have an impact on the biological areas. For instance, cortisol levels rise after a traumatic incident as a result of the hypothalamic-pituitary-adrenal axis. In return, the amygdala produces emotions of fear and anger are linked to excessive cortisol production. In addition to the amygdala, neuroimaging research revealed that early stressors had an impact on certain brain regions. The corpus callosum and other myelinate areas, as well as the volumetric loss in various brain regions, may be adversely affected by early exposure to increased amounts of stress hormones, coinciding with the data stated above.

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6. Impact of Emotion Dysregulation

Increased aggression and impulsivity are known to be associated with BPD. However, no previous study had tested the correlation between hippocampus volume and aggression-impulsivity symptoms in BPD. Therefore, Zetzsche and colleagues aimed to examine the potential relationship between abnormalities in the hippocampus volume and aggressive-impulsive behaviour given the knowledge that the hippocampus regulates aggression and impulse control [5]. Twenty-five female BPD patients and 25 healthy controls were enrolled in the study.

Using MRI, researchers were able to confirm the previous research result about the reduced volume of hippocampus in BPD particularly in the patients with multi-hospitalisation experience. Also, they discovered a strong correlation between lifetime aggressiveness and left hippocampal atrophy. The result supported the prediction that a decrease in hippocampus is negatively correlated with an increase in aggressive behaviour. Two instances investigated in the study—assault and irritability—were negatively correlated with left hippocampus volume. Some researchers have noted that violence and impulsivity may co-occur, but it does not necessarily mean they are inextricably linked [19].

According to Zetzsche and colleagues, not all hippocampus atrophy is negatively correlated with aggression or impulsivity behaviour but solely between left hippocampal atrophy and aggression [5]. Despite the fact that the hippocampus and the amygdala are thought to work cooperatively, the study did not discover evidence to indicate a correlation between aberrant amygdala volume and aggressive behaviour. It is satisfied to say that the abnormal hippocampus volume in BPD could be treated as an indicator for aggressive behaviour, in particular for patients with multi-hospitalisation experiences. Regarding impulsivity, Soloff and colleagues found that it is correlated to the orbital frontal cortex [20]. The relationship between them should be further discussed in future studies.

7. The Diagnostic Advantage of Neuroimaging

The above-discussed research showed that neuroimaging techniques could be used for identifying brain structure and function abnormalities. Incorporating the use of neuroimaging techniques into the BPD diagnosis procedure would reduce the chance of misdiagnosis. Numerous structured and semi-structured interviews are implemented in common psychiatric and general clinics to aid in diagnosing BPD. However, this type of diagnostic method permitted 256 possible combinations of symptoms for the diagnosis of borderline personality disorder [21]. Hence, the approach may raise the possibility of delivering an inaccurate diagnosis. According to Ding and Hu, up to 16 percent of individuals with bipolar disorder (BD) have a BPD diagnosis, according to research [22]. This might be explained by the overlap in symptoms and the numerous behavioural similarities between the two conditions. For instance, BPD and BD would show signs of extreme affective dysregulation and instability. Ding and Hu's report also stated that MRI results showed that the right hippocampus region of the BD group was significantly smaller than that of the BPD group [22]. The BPD group, on the other hand, displayed a decreased bilateral hippocampus volume. This evidence supports that BPD and other psychiatric disorders feature similar brain abnormalities and comparable symptoms. In order to minimise the possibility of making a mistaken diagnosis, professionals could utilise neuroimaging in addition to the diagnostic interview.

8. Selection Bias in the BPD Research

The research conducted for the meta-analyses was primarily based on clinical samples. One gender group may be overrepresented in clinical samples if there is an imbalance in the representation of the gender. As was mentioned at the outset, 1.6% of the general population suffers from BPD. Around 70% of patients in the clinical domain are women [21]. This tendency results in an

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overrepresentation of women because the meta-analyses study is generally generated from clinical samples. According to Busch and colleagues, selection bias may be relatively common in BPD research since studies have a tendency to compare female BPD patients with healthy controls, which prevents results from being generalised to male BPD patients [23]. Hence, it is safe to say that using only clinical samples as a basis for generalising the BPD brain abnormalities condition would not be considered as a valid strategy. Informant reports might be a method for obtaining a relatively generalised finding regarding the potential selection bias. Busch and colleagues observed that gender disparities were only observed in the self-report sample compared to the informant condition when incorporating the informant report approach, such as the BPD dimension and item-level information [23]. Concisely, studying female BPD patients may help researchers investigate the symptoms of BPD and brain abnormalities, but it may fail to provide generalised results.

In summary, this essay analysed neuroimaging studies based on BPD patients. The study discovered that the brain volumes such as the hippocampus and amygdala are altered in people with BPD. Traumas experienced in childhood may cause these anomalies, which are then associated with emotional dysregulation. The accuracy of BPD diagnosis could be considerably improved by combining neuroimaging techniques into diagnostic procedures. Yet, it is apparent from the aforementioned research findings that participants were primarily female BPD patients. For a generalised representation of BPD communities, it is advised that the study include both male and female subjects to avoid gender being a confounding factor that influences the study result.

9. Conclusions

This paper has summarised the neuroimaging research on abnormalities in brain structure and function, the impact of BPD, the possibility that early traumatic experiences contributed to the onset of BPD, the diagnostic benefit of neuroimaging, the challenges faced by the existing neuroimaging research, and the importance of combining neuroimaging within traditional clinic. The overrepresentation of female BPD patients has been hypothesised to affect the data's representativeness. More study on both genders is required to boost generality and better understand how BPD patients differ from healthy controls in terms of brain structures and functions.

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