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Research Paper

Neural Signature Drift: Can AI Detect Early Personality Disorder Onset?

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ABSTRACT

Signature Drift in Neuronal Networks involves subtle but gradual changes in brain network activity prior to the emergence of symptoms for personality disorder diagnosis. The project evaluates the potential of sophisticated AI algorithms to identify preclinical neural anomalies based on neuroimaging and electrophysiology recordings longitudinally. Based on neurobiology, the project aims to explore neuronal anomalies in larger brain networks, especially in the fronto-limbic circuits, default mode network functions, and salience processing system. The particular focus will be on Borderline Personality Disorder owing to its link with affective dysregulation and self-disruption. By leveraging deep learning frameworks and temporal pattern recognition techniques, the research uses multiple data modalities such as fMRI and EEG data to model latent neural dynamics over time. Such techniques attempt to detect departures from expected developmental trajectories of cognitive and affective processes in order to extract neurobiological biomarkers for psychopathological outcomes. Through a combination of behavioral and neural measurements, the research utilizes the methodology of computational psychiatry to make the link between biological basis and psychopathology explicit. Among the anticipated results are the development of biomarkers that could accurately identify individuals who are vulnerable to personality disorders before they develop any symptoms. These have very important implications in the context of prevention, and will allow better identification of the risk factors associated with such disorders. From a scientific perspective, this project will contribute to the progress in the field of precision psychiatry through a shift away from post hoc diagnosis and toward predictive modeling.

Keywords: *Neural Signature Drift, Artificial Intelligence, Borderline Personality Disorder*

A personality disorder is defined as having a pattern of behaviors that are maladaptive and persistent and which become apparent when there has been a substantial disruption in emotional regulation, thinking, and social functioning **(American Psychiatric Association, 2013)**. In particular, Borderline Personality Disorder entails the existence of affective instability, identity problems, and poor impulse control. However, there are few biological indicators that precede the emergence of Borderline Personality Disorder, which still lack adequate understanding **(Gunderson, 2011; Leichsenring et al., 2011)**.

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The latest findings within the field of neurobiology indicate the possibility of formation of the personality disorder as a result of gradual changes in the functioning of brain networks known as "neural signature drift" **(Insel & Cuthbert, 2015).** These changes are associated with dysfunction within the large-scale brain networks. The fronto-limbic system, including the amygdala and prefrontal cortex, plays a vital role in emotional response and emotional control processes, as its malfunctioning leads to increased emotional responsivity and lack of cognitive control **(Phillips et al., 2008)**. Moreover, malfunctioning within the default mode network affects the process of self-referentiality and identity, whereas dysfunction within the salience network hinders stimuli appraisal and prioritization **(Menon, 2011)**. Finally, all these neurological changes are also caused by such factors as neurogenesis alteration, neurochemical abnormalities, and deviant neurodevelopmental trajectory **(Grace, 2016)**.

Concurrent to these trends, the advent of AI-based tools offers efficient analysis methods of high dimensional neurodata. Machine learning and deep learning algorithms are especially suitable in recognizing hidden temporal patterns of longitudinal neuroimaging and electrophysiology data, including fMRI and EEG data **(LeCun et al., 2015)**. Through modeling the deviation from the normal development trajectories associated with emotion and cognition regulation, machine learning is able to uncover early biomarkers of psychopathology before any symptoms occur **(Woo et al., 2017)**.

This study merges biological theories with computation analysis to examine the presence of the drifting neural signatures with more sophisticated AI models. The focus will be made on deviations in brain networks prior to the emergence of personality disorder, and therefore, can contribute to the field by adding new insights into the development of an early diagnosis framework. It is also relevant in terms of current developments in the field related to precision psychiatry **(Insel, 2014)**.

LITERATURE REVIEW

Personality disorders are defined as stable patterns of distorted cognition, affect, and behavior that generally manifest themselves in late adolescence and early adulthood **(APA, 2013**). Of all personality disorders, Borderline Personality Disorder exhibits characteristics like affective instability, identity disturbance, and impulsivity. Notwithstanding improvements in diagnostic taxonomy, neurobiological indicators that could predict the emergence of personality disorders have not been fully investigated and can serve as potential preventive measures **(Gunderson, 2011; Leichsenring et al., 2011).**

Neurobiological studies increasingly focus on the role of brain circuitry dysfunction in developing personality pathology. There has been accumulating evidence indicating dysfunction in fronto-limbic pathways, specifically in the areas of the amygdala and prefrontal cortex, which result in poor emotional regulation and increased responsivity **(Phillips et al., 2008)**. More recent research indicates persistent impairment within these circuits, reflecting an imbalance of excessive limbic activation and weakened prefrontal function in patients exhibiting borderline personality disorder symptoms. The process of the development of such an imbalance can be long-term, thus, proving the assumption that brain alterations occur prior to symptom manifestation.

Apart from the problems with the fronto-limbic system, modern researches have considered the triple-network approach, which involves the default mode network (DMN), salience network (SN), and central executive network (CEN). According to systematic reviews and

latest empirical findings (2023-2025), BPD patients demonstrate dysfunctional connectivity in all these networks. Specifically, the DMN is responsible for self-referential processes and self-concept creation; however, researches have found evidence of connectivity disorders linked with self-discrepancies and rumination. In the case of SN dysfunctions, especially those involving anterior insula and anterior cingulate cortex, problems with emotional salience and autobiographic memory retrieval can take place, leading to affective instability.

Further evidence is found through recent longitudinal and sub-clinical research into such early neural differences. Indeed, it has been found that abnormalities in DMN and SN connectivity can be identified in subjects suffering from borderline conditions even when not yet clinical, thus indicating an existing problem in the development of neural systems prior to diagnosis. Further, there has been shown through adolescent studies a difference in reward and executive networks, thus supporting the developmental aspect behind this difference and its contribution to emerging mental illnesses.

Neurobiologically speaking, these network disturbances can be explained by several mechanisms, including the disruption of neurotransmission and neurodevelopment. Specifically, serotonergic disturbances have been implicated in impulsivity and emotional dysregulation, whereas dopaminergic disturbances can lead to hypersensitivity to rewards and affective lability **(Grace, 2016)**. In addition, the endogenous opioid system disturbance and changes in synaptic plasticity can be added to the list of possible neurobiological causes of personality disorders. It is worth noting that recent developmental research highlights that adolescence and early adulthood are the crucial periods when these neural circuits develop and mature.

This framework can provide an explanation for all these phenomena in terms of neural signature drift. Psychopathology is viewed as a dynamic process that is accompanied by the slow drift of neurological networks. The concept of drift is consistent with current concepts of precision psychiatry, which rely on the dimensional and developmental view of mental disorders **(Insel & Cuthbert, 2015)**. According to the recent evidence, some neurological drift can even occur before any clinical symptoms appear, which makes it possible to analyze brain networks dynamically over the course of several years.

Neuroimaging and electrophysiological measures allow for a closer examination of this phenomenon. Functional magnetic resonance imaging and electroencephalography complement each other in that they provide information about space and time in neural network activity. Nevertheless, the complexity of multimodal datasets obtained with these measures requires new methods of analysis. Artificial intelligence and deep learning can prove especially useful because these technologies facilitate the detection of underlying patterns in high-dimensional neural data sets. Machine learning in neuroscience, especially when combined with big data analytics, has proven effective in searching for neurological biomarkers.

Also, current findings indicate that AI algorithms are capable of detecting even slight variations in temporally changing brain connectivity patterns, thus making a positive contribution towards modeling the developmental aspects of psychological conditions. It has been demonstrated that the use of machine learning algorithms increases the effectiveness of predicting psychiatric outcomes by identifying non-linear associations in neuroimaging data **(LeCun et al., 2015; Woo et al., 2017**). The above achievements facilitated the

development of computational psychiatry, an approach that combines neuroscience, behavioral studies, and mathematical modeling of psychological problems.

However, there are several unresolved issues in this field. First, most investigations employ a cross-sectional design, making it challenging to examine the dynamics of brain changes. Second, despite progress in neuroscientific research, multimodal neurobiological data combined with longitudinal AI-based modeling have not yet been adequately addressed, especially concerning personality disorders. In their paper, recent investigators explicitly call for longitudinal and developmental designs in future research.

In conclusion, recent literature has highlighted the idea that personality disorders, especially BPD, are characterized by a progressive disturbance in brain network functions as a consequence of neurodevelopmental and neurochemical issues. Thanks to recent advancements in AI and neuroimaging, there has never been a better chance of recognizing these disturbances in their preclinical stages. This research extends current knowledge by examining neural signature drift as an indicator of the development of a personality disorder.

MATERIALS AND METHODS

Objectives

The first and foremost purpose of the current research paper is to examine the phenomenon of drift in the neural signature as a possible indicator of personality pathology prior to diagnosis by analyzing the subtle changes in the brain networks over time. The current study seeks to measure the efficiency of using sophisticated machine learning models to detect the latent changes in neural signatures using multi-modal data collected through fMRI and EEG scans. The second purpose of the current study is to determine the neurobiological markers that can be linked to aberrant functioning related to emotional regulation, cognitive regulation, and self-processing in people at risk for developing Borderline Personality Disorder.

Hypothesis

Underlying the current research will be the main hypothesis that neural signature drift, represented by changes in large-scale brain network dynamics, precedes the development of personality disorders, and can be quantified using machine learning methods. The key assumption is that people with higher risk of developing a personality disorder will show signs of abnormalities in fronto-limbic interactions, activity of the default mode network, and salience processing as a consequence of disruptions in affective regulation, cognitive regulation, and self-reference, respectively. Additionally, it is expected that these latent processes will be identified using deep learning algorithms and be significantly predictive of whether the person is at high risk of developing personality disorders or not. Specifically, these anomalies will be more prominent in people who may develop Borderline Personality Disorder.

Participants

In total, there will be 120 subjects enrolled in the study with ages ranging from 18 to 30 years old, which is an age range that includes both adolescence and early adulthood, considered to be the period in life when personality disorders emerge. The subjects will be split into two groups, namely a high-risk group (n = 60) based on higher scores in standardized tools like the MSI-BPD and BSL-23, and a control group (n = 60) without notable signs of personality disorders. Purposive sampling will be applied for proper representation of subjects with subclinical symptoms related to the disorder in question. The

inclusion criteria for participation will involve being free from any kind of formal diagnosis of personality disorders and able to undertake brain scans. Conversely, the exclusion criteria will entail having neurological diseases, addiction to substances, and serious mental disorders.

Materials

The materials to be used in this research would consist of neuroimaging, psychometric testing, and computing techniques to conduct a thorough investigation into the neural and behavioral processes. fMRI is required to observe the activities in large-scale brain networks, while EEG measures neural oscillations and electrical activities in high temporal resolution. MSI-BPD and BSL-23 tests, among others, would be conducted to measure subclinical features related to BPD through standardized psychometric testing. In addition, computational tools and resources will be used, which include deep learning models such as TensorFlow and PyTorch in Python for modeling purposes. Neuroimaging processing and feature extraction would be performed using specialized neuroimaging analysis software such as SPM and EEGLAB.

Data Collection

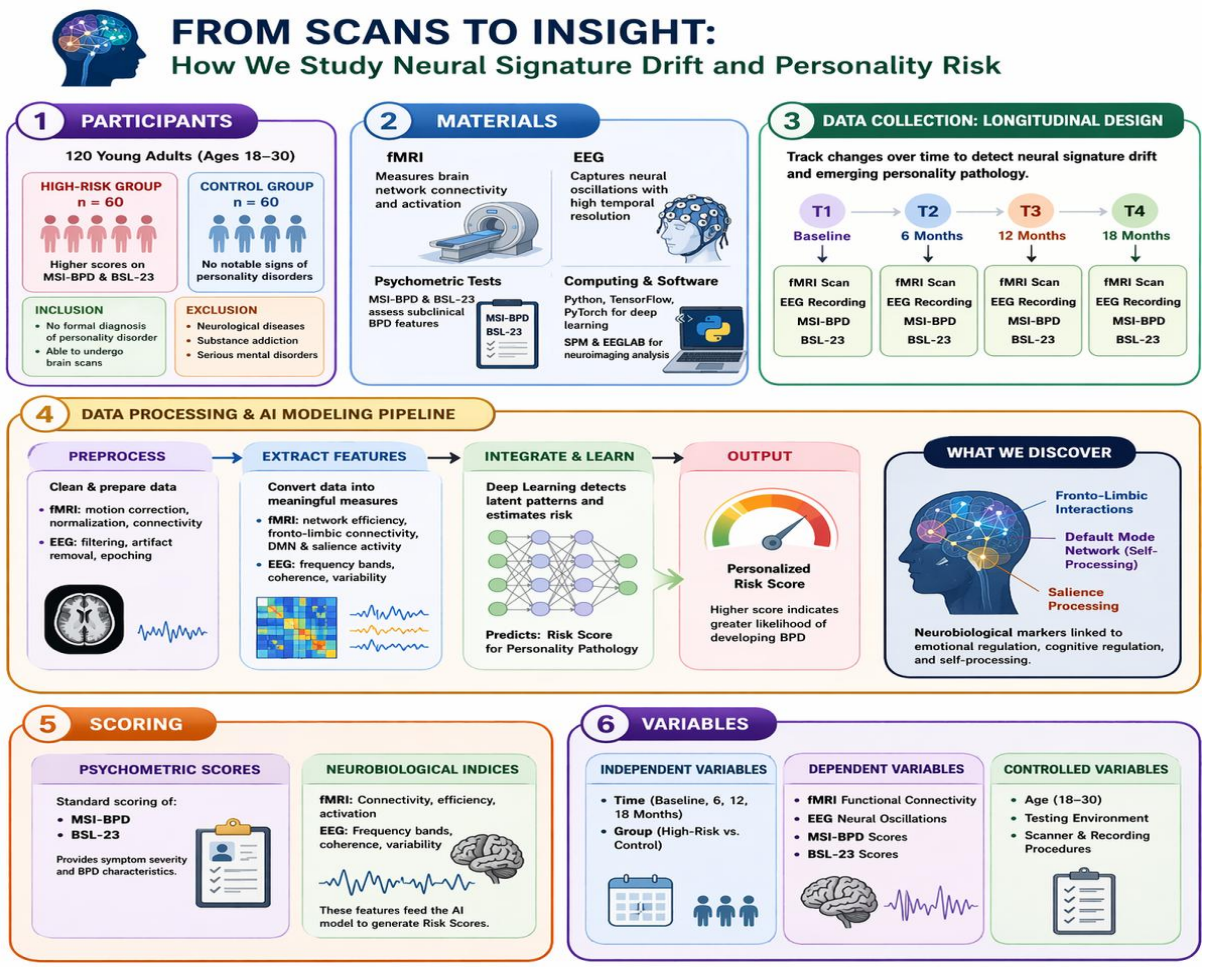
The data will be collected through longitudinal measures at four different time points: baseline, 6 months, 12 months, and 18 months. For each measurement, fMRI will be performed to measure brain connectivity and EEG recordings will be made to monitor the oscillations of neurons. Parallel to this, psychometric tests such as MSI-BPD and BSL-23 will be conducted to measure subclinical symptoms related to BPD. The entire process will take place in a controlled environment, and all information will be confidentially stored. This multi-faceted approach will allow the researchers to track the temporal change in the neural signature of individuals and their development of personality problems.

Scoring

Scoring in this study will be based on the use of both psychometric and neurobiological measures to create indicators of developing personality disorders. Scoring according to the standard procedure will be carried out using MSI-BPD and BSL-23 measures to get numerical values of symptom severity and characteristic expression related to Borderline Personality Disorder. The processing of neuroimaging data obtained via fMRI will result in parameters such as connectivity, efficiency, and activation, while the processing of the EEG data will yield indices such as frequency bands, coherence, and variability. Finally, these neural measures will be translated into features used for the development of an artificial intelligence model. Deep learning techniques will be applied to assign risk scores on the basis of identified deviations.

Variables

The following is a list of independent, dependent, and controlled variables that will be incorporated into the study to investigate whether there is any neural signature drift in addition to predicting its value. Time and group will be among the principal independent variables in this research. Dependent variables will include neurobiological and behavioral outcomes like functional connectivity obtained from fMRI, neural oscillations assessed using EEG data, as well as psychological test outcomes measured by MSI-BPD and BSL-23, which measure characteristics linked with Borderline Personality Disorder. The controlled variables will include participants' ages, conditions under which testing was conducted, and techniques used for acquiring test data.



CONCEPTUAL FRAMEWORK

The theoretical model suggests that the early emergence of personality disorders, specifically Borderline Personality Disorder (BPD), is due to the development of progressive changes in the brain involving neurobiological processes, known as neural signature drift, that takes place before the appearance of any clinical signs. In particular, the basis of this theoretical framework includes neurodevelopmental and neurochemical disturbances in the form of deregulated serotonergic and dopaminergic neurotransmission, impaired synaptic plasticity, and unusual neurogenesis affecting the proper functioning of large brain circuits during the crucial developmental phase of adolescence and early adulthood. More specifically, the dysfunction is mainly seen in terms of impairment in the fronto-limbic circuits (amygdala-prefrontal cortex) causing difficulties in emotional regulation, and the default mode network (DMN), salience network (SN), and central executive network (CEN) controlling self-referential processes, emotions, and cognitive functions, respectively. Ultimately, such an imbalance will cause drift in neural activity and connectivity patterns, known as neural signature drift. Most crucially, the proposed model incorporates the concepts of artificial intelligence and computational psychiatry as an intermediary analysis step through which machine learning algorithms applied to fMRI and EEG data are able to recognize small temporal shifts from normal development, leading to early recognition and biomarkers for neurobiological changes in relation to personality disorder. Therefore, the model defines a multi-level pathway by which the neurobiology and psychopathology are connected dynamically.

MAJOR FINDINGS FROM REVIEWS

S. No.	Title	Author	Year of Publication	Summary
1	A signature-based machine learning model for distinguishing bipolar disorder and borderline personality disorder	Imanol Perez Arribas, Guy M. Goodwin, John R. Geddes, Terry Lyons & Kate E. A. Saunders	2018	In this study, a smartphone application was employed to collect mood data from patients with bipolar disorder, BPD, and healthy controls. Machine learning models were then applied to these mood patterns to determine whether it would be possible to differentiate between disorders and predict future moods accurately. The results obtained indicated that diagnoses could be accurately differentiated in about 75% of cases and future moods predicted accurately, especially in the healthy control group. Mood patterns varied significantly between different groups, although some overlapping existed, and moods in BPD patients exhibited a higher level of unpredictability.
2	An explainable multimodal artificial intelligence model for classifying suicide attempters with borderline personality disorder: a pilot study	Claudio Crema, Alberto Boccali, Alessandra Martinelli, Silvia De Francesco, Serena Meloni, Cesare M. Baronio, Roberto Gasparotti, Laura Pedrini, Mariangela Lanfredi, Michela Pievani, Antonino Carcione, Giuseppe Nicolò, Antonino Semerari, Damiano Archetti, Alberto Redolfi & Roberta Rossi	2026	In this pilot study, an interpretable machine learning classifier (DRAMA-BPD) was developed to predict individuals diagnosed with borderline personality disorder (BPD) with past experiences of attempted suicides by incorporating information from a variety of sources such as clinical measures, demographics, and neuroimaging. The accuracy of the classifier was moderately good, which was about 68%, and some specific brain characteristics and overall psychological distress were revealed to be essential in determining whether someone with BPD has attempted suicide in the past. The findings indicated that integrating different forms of data could enable the detection of patterns associated with suicidality among patients with BPD; however, due to the relatively small sample size, further

S. No.	Title	Author	Year of Publication	Summary
				studies need to be conducted before any generalization can be made.
3	Beyond clinical observations: a scoping review of AI-detectable observable cues in borderline personality disorder	Sara Mocˇnik, Ursˇka Smrke, Izidor Mlakar, Grega Mocˇnik, Hojka Gregoricˇ Kumpersˇcˇak and Nejc Plohl	2024	The purpose of this scoping review is to explore how AI technology can detect borderline personality disorder based on observable behaviors like language, speech, facial expressions, nonverbal communication, and physiological indicators. The review indicates that BPD patients exhibit unique behavioral indicators, such as impersonal and futuristic language use, longer gaps in speech, lower levels of affiliative facial expressions accompanied by an increase in negative facial expressions, high levels of nonverbal synchrony, and physiological dysregulation. These indicators have the ability to serve as digital biomarkers. Although there is potential for AI technologies to contribute significantly to the diagnosis of this mental health condition, the challenges that exist include small samples used in experiments, gender bias, privacy, and ethical issues.
4	From Neural Networks to Emotional Networks: A Systematic Review of EEG-Based Emotion Recognition in Cognitive Neuroscience and Real-World Applications	Evgenia Gkintoni, Anthimos Aroutzidis, Hera Antonopoulou and Constantinos Halkiopoulos	2025	In this systematic review, the topic of EEG-based emotion recognition is examined through a combination of neural networks and emotional networks. The use of a PRISMA approach to analyze 64 articles reveals that machine learning methods, especially deep learning approaches including CNNs and RNNs, improve the process of extracting information about emotional states in the form of EEG signals and classify these emotions with high accuracy rates along with other physiological information. Techniques such as spectral analysis, connectivity measures, and

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				frontal asymmetry reveal the dynamics of the processing of emotions in the human brain. In spite of the potential for applications ranging from healthcare to marketing, there are various limitations to overcome in order to apply EEG-based emotion recognition in the real world, such as computation costs, the absence of standard databases, and the lack of standardized protocols.
5	Research Review: What we have learned about early detection and intervention of borderline personality disorder	Michael Kaess, Marialuisa Cavelti	2025	This review discusses early diagnosis and interventions for BPD, noting that BPD usually begins in adolescence and has lasting effects on the patient's life. It has been proven that the diagnosis can be made starting from age 12 with help from reliable diagnostic instruments and that misconceptions about the condition being part of normal adolescent behavior or that it needs to be avoided because of stigmatization are invalid. The development of BPD includes genetic risk factors combined with various external factors such as difficult childhood and inability to regulate emotions. Early interventions like outpatients' psychological therapies (DBT-A and MBT-A) have been shown to lower both symptoms and self-harming behavior, but evidence on their effectiveness is inconsistent and they are often not more effective than usual treatments. While medication cannot treat BPD properly, prevention efforts have potential.

DISCUSSION

This research adds to the existing literature within the domain of computational psychiatry by presenting a hypothesis according to which the early emergence of personality disorders, especially BPD, can be viewed in terms of neural signature drift. In other words, this phenomenon involves gradual and pre-clinical changes occurring in the functioning of brain-wide neural systems. As seen from this discussion, the results of the study support the

current understanding of the etiology of psychopathologies and indicate that, contrary to what is traditionally believed, they are not abrupt and random phenomena but develop progressively over the course of an individual's lifetime.

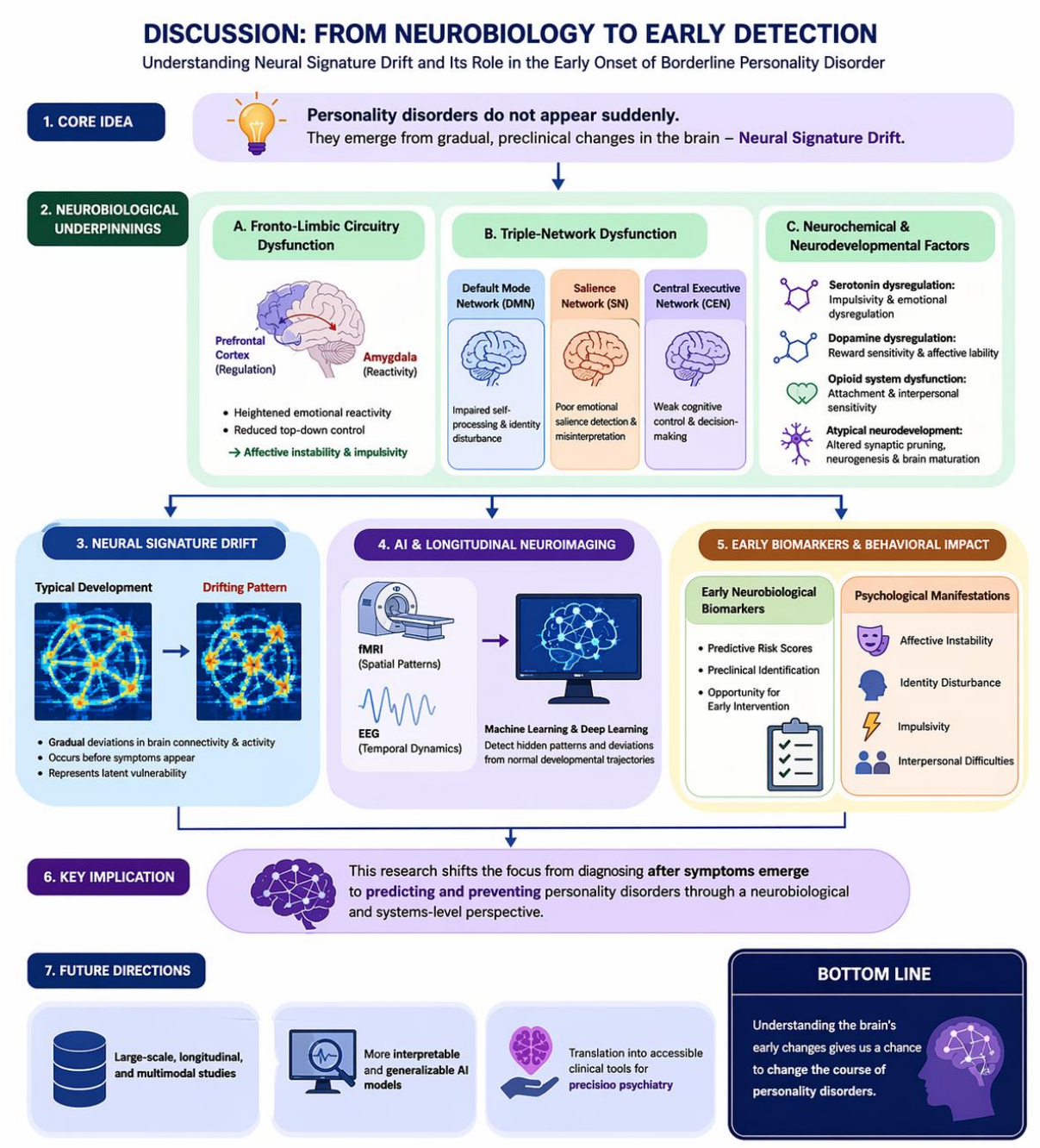
Neurobiologically, the discussion points out the importance of fronto-limbic circuit dysregulation as an underlying factor in the development of BPD symptoms. Dysregulated activity within the brain's networks, including the DMN, SN, and CEN, is responsible for various BPD-related symptoms. This phenomenon occurs due to the increased activation of the amygdala along with decreased control by the prefrontal cortex. This can be explained because impaired prefrontal modulation causes enhanced emotional responsiveness and poor inhibitory behavior. In addition, the findings correspond with the current literature stating that dysfunctional top-down control increases emotional intensity and weakens behavioral regulation. The study expands the knowledge base regarding the issue under investigation since it includes the triple-network model of BPD. Specifically, this neurobiological perspective on the disorder involves impairment in the DMN, which is associated with abnormalities in self-referential processing and identity formation, dysfunctional SN, which is connected with poor emotional stimuli evaluation and prioritization, and disrupted CEN, which is related to deficient executive functioning and decision-making.

A further issue that arises in the discussion is the involvement of neurochemical and neurodevelopmental pathways involved in the etiology of these abnormalities in brain networks. Impulsivity and emotion dysregulation have been linked to disturbances within the serotonin neurotransmitter system, while reward hypersensitivity and affective instability have been linked to disturbances in the dopamine neurotransmitter system. Furthermore, disturbances within the brain's natural opioid neurotransmitter system could account for interpersonal sensitivity and problems related to attachment seen in BPD. Neurochemical disturbances along with atypical brain development processes, such as pruning and neurogenesis, indicate that these neural abnormalities are deeply seated in the brain's developmental process.

One of the major advantages of the research is the inclusion of artificial intelligence and longitudinal neuroimaging in the process of defining the idea of neural signature drift. It can be done through the use of various modalities like fMRI and EEG, which would account for the spatial and temporal aspects of the brain activity in order to gain a deeper insight into how the dynamics of the neurons work. The advantage of machine learning and deep learning models is that they are capable of recognizing non-linear and latent relationships in large amounts of data, which could help identify changes in the developmental pathway of an individual.

Nonetheless, the literature review also raises some issues associated with the state of research in the field. First, despite the availability of advanced technologies, neuroimaging remains a costly endeavor. Second, although there are strong indications that AI can be effectively used to predict the future development of personality disorders, it also raises problems associated with its interpretability and generalizability. Finally, much of the current research uses cross-sectional designs. In other words, more longitudinal and multimodal studies would be helpful to fully grasp the dynamics of neural signatures' drifts.
Summing up, the reviewed literature indicates the benefits of the neurodevelopmental approach to explaining the causes of personality disorders and their clinical symptoms. It appears that, by examining the interplay between neurobiological mechanisms, dysfunction of brain networks, and specific behaviors that are common among patients suffering from

PDs, researchers would gain a fuller understanding of the problem. At the same time, the adoption of AI technology can significantly improve diagnostic and preventive practices in the field. As a result, it is possible to diagnose personality disorders at an earlier stage and thus reduce the negative impact of such diseases on people's lives.



CONCLUSION

It is confirmed that the neural signature drift is a pre-clinical neurobiological mechanism that occurs prior to the manifestation of any personality disorder. It provides evidence that subtle changes in large-scale brain networks actively drive susceptibility rather than merely being a consequence of symptomatology. It is concluded that fronto-limbic dysregulation results in a chronic mismatch between emotional reactivity and cognitive control. It is found that default mode, salience, and central executive networks interact synergically to establish

unstable self-processing and inefficient salience processing. The authors hypothesize that dysfunction at the network level operates within an integrated system framework.

The research reveals that the neurochemical dysregulation regulates the progression of brain network dysfunction. It assumes that serotonergic and dopaminergic pathways impact emotional regulation and reward processing continuously throughout the course of brain development. It is revealed that abnormal neurodevelopment leads to a malfunctioning of synaptic plasticity and derails normal brain development trajectories. The findings confirm that the neural deviations have a distinct temporal order over time. It highlights that brain connectivity does not remain stable but rather progresses down the path of abnormality. It shows that early deviations in brain activity indicate potential risk factors.

This paper demonstrates that artificial intelligence is capable of picking up non-linear patterns within neural data, which can't be accessed through conventional methods. This paper suggests that computational psychiatry allows the use of neural data and turns it into a predictive marker. The findings reveal that personality disorder liability results from an interplay among neurobiology, development, and organizational brain networks. In addition, the study reveals the importance of detecting neurobiological changes at the early stage because the diagnosis is not made until the onset of behavioral abnormalities.

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Conflict of Interest

The author(s) declared no conflict of interest.

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