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Review Article

Brain and Smartphone Addiction: A Systematic Review

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In recent years, the smartphone has become ubiquitous in everyone's lives. The smartphone has both positive and negative impacts on the users. Although addiction has been extensively studied, not much has been done to examine the association between neurofunctional regional activation and problematic smartphone use. This review, therefore, is systematically aimed at understanding the different neurofunctional regional activation differences related to smartphone addiction. The systematic review was done in four stages as follows: (1) identifying the techniques/instruments used in the literature (database search), (2) identifying relevant literature, (3) identifying criteria for inclusion and exclusion, and (4) acquiring full-text papers. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were used to conduct the systematic review. The literature was searched using the following databases: PubMed, Science Direct, Taylor & Francis, and Springer Link. The inclusion requirements were met by 7 articles out of 28896. The study on smartphone addiction with a focus on neurofunctional regional activation is limited. This review sheds light on neurofunctional regional activation associated with problematic smartphone usage. This will open the door to focused interventions and well-informed approaches to digital well-being in our technologically advanced society.

1. Introduction

In the contemporary digital landscape, the increased use of smartphones has spread around the world and permeated every aspect of everyday life. The ubiquity of smartphones has transformed the way individuals interact with information, socialize, and navigate daily routines.

According to Derevensky et al. [1], problematic mobile phone use (PMPU) is also known as smartphone addiction, mobile phone dependence, and mobile phone addiction. Therefore, problematic mobile phone use and smartphone addiction were used interchangeably in this review.

The extensive use of smartphones has raised concerns about potential behavioral addictions, with smartphone addiction emerging as a recognized and growing issue. Overuse of smartphones has been linked to a few health issues, including mental and medical conditions. According to Wacks and Weinstein [2], medical issues include poor eating habits, pain, headaches, decreased physical fitness, and difficulty sleeping. Addiction to smartphones has been linked to anxiety and depression [3]. Additionally, studies have linked it to increased impulsivity, indications of alcohol use disorder, and psychological discomfort mediated by emotional dysregulation [4, 5].

Understanding the cognitive effects of our digitally linked lifestyles has grown increasingly dependent on research into the neurofunctional regional activation variations associated with smartphone usage and the growing issue of smartphone addiction. Neurofunctional regional activation refers to the observable and measurable patterns of activity within specific regions of the brain during various cognitive tasks, stimuli, or conditions [6]. The neurofunctional regional activation framework provides a means to explore how the brain responds to the stimuli of smartphone use, shedding light on the potential neural correlates of addictive behaviors.

The advances in neuroimaging methods have made it possible for scientists to investigate the neurofunctional regional activation patterns linked to cognitive tasks and stimuli. Examples of these methods include electroencephalography (EEG) and functional magnetic resonance imaging (fMRI) [7, 8].

With the use of these techniques, researchers observe and measure patterns of neural activity associated with specific tasks, behaviors, or cognitive processes. Understanding functional changes is important for investigating the impact of experiences, learning, and environmental influences on the brain, as well as for comprehending the underlying processes of many neurological and psychiatric diseases. They contribute to a thorough understanding of neurobiology by shedding light on how the brain interprets information, controls behavior, and adjusts to various situations.

Neuroimaging studies in this realm identify specific brain regions involved in reward processing, executive functions, and cognitive control, elucidating the impact of prolonged smartphone engagement on these crucial cognitive processes. This comprehensive review is aimed at compiling scientific information about neurofunctional regional activation associated with problematic smartphone use.

2. Methods and Search Strategy

This review followed the PRISMA guidelines [9]. The literature was retrieved by the researcher using well-known database sources such as PubMed, Science Direct, Taylor & Francis, and Springer link citations and references, from January 2012 to March 2023. The study contained bibliographical lists of all brain studies connected to smartphone use, with the search process limited to articles published in the English language.

The search for pertinent literature started on April 1, 2023. Each database was searched by title or abstract. The following combination of terms and keywords were used in the search: "Smartphone addiction" or "Mobile Phone Addiction or "Mobile Phone Addiction Tendency" or "Smartphone Overuse or "Problematic Smartphone Use" or "Excessive Mobile Phone" or "Brain" or "Brain Structure" or "Brain Function".

2.1. Eligibility Criteria. In this review, the PRISMA statement was closely followed to establish the standards to obtain, include, screen, and exclude the documents. The following qualifications were to be eligible for the studies that were being evaluated. The following components must be included in the research: (1) smartphone addiction/problematic smartphone use, (2) smartphone addiction and different neurofunctional regional activations, and (3) English only. The following exclusion criteria were considered: (1) documents that have been previously published, (2) meta-analyses and reviews of the literature, (3) articles that contain an abstract but no full text, and (4) publications with incomplete or erroneous outcome data.

2.2. Data Extraction. The researcher conducted a literature search and gathered pertinent information. After screening, data extraction, cross-checking, and analysis, the final decision on the articles was made by the researcher. The following general information was gathered: (1) author, title, and year of publication and (2) papers discussing various neurofunctional regional activations linked to problematic smartphone use.

3. Results

Figure 1 shows the search results. There were a total of 28896 records found. Following the elimination of duplicates and applying the inclusion and exclusion criteria, 228 articles were sought for retrieval, with 45 full-text articles obtained and examined. To find eligible research, the references, citations, and quality of the included papers were examined, yielding 39 more papers. The review included 7 papers that satisfied the requirements (Table 1).

The advancements in neuroimaging techniques have led to a growing body of research on the changes in brain structure and function associated with addictive behaviors. Considering a few previous studies, Li et al.'s [11] functional near-infrared spectroscopy study demonstrated that smartphone addiction influences creative cognition (i.e., the ability to transcend semantic restrictions). The study revealed that the prefrontal brain and temporal areas of smartphone addiction tendency participants were less active during the Alternate Uses Task (AUT) than the healthy control group. Wu et al. [12] conducted a longitudinal study that employed intrinsic functional connectivity (iFC) analysis (based on the observation that activity levels in distant brain regions often exhibit strong connections by [13]). The results revealed that the group with problematic mobile phone use had higher levels of left inferior frontal gyrus (IFG), left occipital gyrus (OcG), right orbital gyrus (OrG), left OcG and left parahippocampal gyrus (PhG), and right middle temporal gyrus (MTG). The left PhG and right MTG are crucial in the link between problematic smartphone use and depression. These brain regions are of particular interest due to their known involvement in memory, emotional processing, and other cognitive functions. By investigating the moderating role of specific brain connectivity patterns, the study provides a nuanced understanding of the complex interplay between PMPU and depressive symptoms. Problematic smartphone use (PSU) has a negative correlation with grey matter volume (GMV) of the right fusiform gyrus and anterior cingulate gyrus inversely correlated with fractional anisotropy (FA) in the body of the corpus callosum. This study delves into the neurobiological mechanisms involved, aimed at understanding how the anterior cingulate gyrus, with its role in emotional and cognitive processes, might contribute to or mitigate the development of depressive symptoms in the context of problematic mobile phone use [14]. FA is a method used to emphasize and evaluate white matter fiber tracts. Among the problematic smartphone users, there was a considerable reduction in the superior cerebellar peduncle (SCP) volume. The reduced volume in this brainstem substructure may have implications for neural function, potentially impacting physiological processes regulated by the brainstem, such as autonomic functions, sensory processing, and motor control [15]. By detecting structural alterations in a particular brainstem substructure, this work adds to our understanding of the impacts of problematic smartphone usage and illuminates the possible neurobiological causes of PSU in adolescents. The right lateral orbitofrontal cortex (OFC), a part of the brain linked to decision-making, emotional processing, and social behavior,

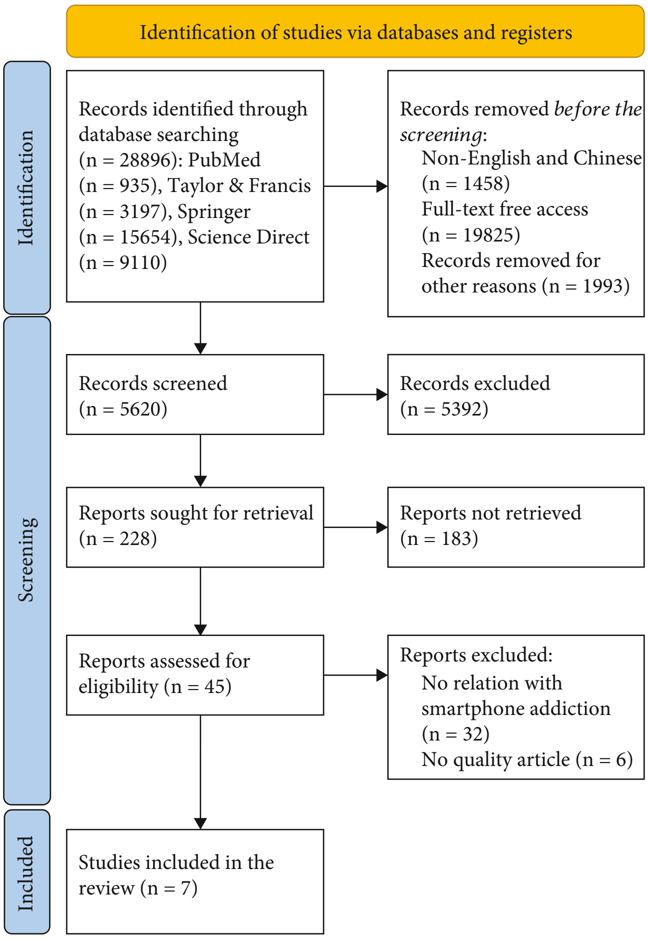

Figure 1: PRISMA flow diagram. Note. From [10].

showed reduced GMV in problematic smartphone users. This suggests that problematic smartphone use may be caused by a loss of regulatory control over previously reinforced behaviors [16]. The grey matter abnormalities in the lateral orbitofrontal cortex among individuals with problematic smartphone use suggest potential structural alterations in a brain region associated with decision-making and emotional processing. A resting-state fMRI study using region of interest (ROI) to ROI analysis revealed that adolescents who used their smartphones excessively had lower functional connectivity between the nucleus accumbens and OFC, as well as between the middle cingulate cortex and OFC [17]. This suggests that the neural communication between the frontal cortex and striatum may be affected in individuals exhibiting problematic smartphone use. Focusing on frontostriatal connectivity, it provides valuable information about the brain's role in the development and maintenance of problematic smartphone use. In the dorsolateral prefrontal cortex (DLPFC) and dorsal anterior cingulate cortex (dACC), excessive smartphone users had more neuronal inactivation than the control group after displaying an angry face and emotional change. The use of smartphones excessively is likely to result in decreased cognitive control while processing emotions, which may change the emotional processing associated with social interaction [18]. This suggests that the neural mechanisms involved in interpreting facial emotions may be affected in those who engage in problematic smartphone use.

4. Discussion

The purpose of this systematic review was to focus on different neurofunctional regional activations associated with smartphone addiction.

4.1. Decreased Cortical Activations and Functional Connectivity. Reductions in cortical activations and functional connections are observed in the prefrontal and temporal cortices in smartphone addicts. These regions are critical for complex cognitive processes and adaptive behavior. This reduction may contribute to challenges in establishing novel associations and generating creative ideas [11].

4.2. Language, Emotional, Auditory, and Visual Processing. Problematic smartphone users show difficulties in language processing, emotional processing, auditory processing, and visual information processing. These challenges extend to poor self-control, moral reasoning ability, memory issues, and difficulty in regulating impulses [12]. In particular, the anterior cingulate gyrus, the right fusiform gyrus, and the fractional anisotropy in the corpus callosum body were negatively correlated between PSU and brain anatomy [14].

4.3. Correlation with Corpus Callosum and SCP Volume. Problematic smartphone use is negatively correlated with FA values in the corpus callosum body, indicating potential disruptions in white matter connectivity between hemispheres. Reduction in SCP volume is associated with poor motor functions, balance, and cognitive processes [15].

4.4. Impact on the Right Lateral Orbitofrontal Cortex (OFC). The right lateral OFC, responsible for emotional processing, decision-making, and social behavior, shows low GMV in problematic smartphone users. This decrease has been connected to several mental health conditions, such as addiction, anxiety disorders, and depression [16].

4.5. Reward System and Functional Connectivity. Excessive smartphone use is associated with lower functional connectivity between brain regions involved in the reward system, such as the OFC, nucleus accumbens, and middle cingulate cortex. These areas are crucial for processing rewarding stimuli, and disruptions in their activity may contribute to addictive behaviors [17].

4.6. Neuronal Deactivation in DLPFC and dACC. More neuronal deactivation is seen in the dorsolateral prefrontal cortex (DLPFC) and dorsal anterior cingulate cortex (dACC) in those who use smartphones excessively. This suggests potential neural adaptations and disruptions in the brain's reward circuitry, affecting attentional control and decision-making processes [18].

Table 1: Details of the reviewed papers.

S. No.	Author	Year	Tools/techniques	Sample size	Result	Insight	Contribution
1	Li et al.	2022	Smartphone Addiction Scale, State-Trait Anxiety Inventory -State Scale, Raven's Standard Progressive Matrices, and Beck's Depression Scale-II	503 students	The prefrontal cortex (PFC) and temporal areas show altered brain activity and functional connectivity patterns in the context of an addiction to smartphones, which significantly impacts one's ability to think creatively.	The detrimental effects of smartphone addiction on creative cognition were seen in the PFC and temporal regions' brain activity and functional connection patterns.	This discovery has promising ramifications for exposing the harmful impacts of smartphone addiction on people's higher-order cognitive processes.
2	Zou et al.	2022	Self-rating questionnaire for adolescents, PMPU, Depression Anxiety Stress Scale-21, MRI, and fMRI	The baseline MRI scan was completed by 268 students, and the criterion of image preprocessing included 238 college students	The intrinsic functional connectivity (iFC) analysis of the left inferior frontal gyrus (IFG), left occipital gyrus (OcG), right orbital gyrus (OrG), left OcG and left parahippocampal gyrus (PhG), and right middle temporal gyrus (MTG) was higher in the group of college students with problematic mobile phone use than in the group without problematic mobile phone use.	This study sheds light on the neurological processes that underlie the association between depressed symptoms and excessive mobile phone use.	The article adds to the expanding corpus of research on the connection between mental health, brain function, and technology use.
3	Zou et al.	2021	MRI, PMPU, and Patient Health Questionnaire-9	266 students	The anterior cingulate gyrus and right fusiform gyrus both had lower grey matter volume (GMV) as a result of smartphone use. In the corpus callosum body, fractional anisotropy (FA) and PMPU have an inverse relationship.	The research sheds light on neurobiological mechanisms at play to comprehend how the anterior cingulate gyrus, which is engaged in emotional and cognitive functions, may either exacerbate or lessen the onset of depression symptoms when used in conjunction with problematic mobile phone use.	The study adds to the body of research on the connection between technology usage, brain function, and mental health by focusing on the anterior cingulate gyrus, a crucial brain area, and its moderating role.
4	Cho et al.	2021	Smartphone Addiction Proneness Scale, Beck's Depression Inventory (BDI), Brief Self-Control Scale, Korean-Wechsler Adults Intelligence Scale, and Structural MRI Acquisition	87 adolescents	Unlike other brainstem substructures, the volume of the superior cerebellar peduncle (SCP) was drastically reduced. Furthermore, the degree of problematic smartphone use (PSU) is related to a decrease in SCP volume.	The study establishes a link between the observed structural changes and problematic smartphone use, suggesting that excessive use of smartphones may contribute to alterations in the anatomy of this brainstem substructure.	The study sheds light on the possible neurobiological causes of PSU in adolescents by detecting structural alterations in a particular brainstem substructure, which advances our knowledge of the consequences of problematic smartphone usage.

Table 1: Continued.

S. No.	Author	Year	Tools/techniques	Sample size	Result	Insight	Contribution
5	Lee et al.	2019	Smartphone Addiction Proneness Scale (SAPS) test, Internet Addiction Test and The Barratt Impulsiveness Scale version 11, BDI, Beck's Anxiety Inventory, and Alcohol Use Disorder Identification Test (AUDIT)	39 problematic smartphone users and 49 male and female users under normal control	In the right lateral orbitofrontal cortex (OFC), smartphone users displayed lower GMV than nonusers.	The main finding of the study is that those with problematic smartphone use had anomalies in the lateral orbitofrontal cortex related to grey matter. This demonstrates the connection between structural alterations in this brain region and heavy smartphone use.	By detecting certain structural changes in the lateral orbitofrontal cortex, the research advances our knowledge of problematic smartphone usage. This data might improve our understanding of the neurological processes that underlie PSU.
6	Chun et al.	2018	Korean SAPS for Youth, the K-Scale, BDI, Beck's Anxiety Inventory, Wechsler Intelligence Scale for Children, Korean (4th edition), and Functional and Structural MRI	38 adolescents who used their smartphones excessively and 42 healthy controls	Researchers discovered that teenagers who used smartphones excessively had reduced functional connectivity between the orbitofrontal cortex, the middle cingulate cortex, and the nucleus accumbens in a resting-state functional magnetic resonance imaging (fMRI) study that used ROI to ROI analysis.	This study offers insight into how neural communication between the frontal cortex and striatum may be affected in individuals exhibiting problematic smartphone use.	The research adds to our understanding of the neural underpinnings of smartphone use, particularly in the adolescent population. Focusing on frontostriatal connectivity provides valuable information about the brain's role in the development and maintenance of problematic smartphone use.
7	Chun et al.	2017	SAPS, Behavioral Inhibition Scale and Behavioral Activation Scale, Facial Emotion Discrimination, and Image acquisition through fMRI and Structural MRI	Heavy smartphone users (25) and normal control users (27)	When an angry visage and an emotional transition were displayed, the dorsolateral prefrontal cortex (DLPFC) and dorsal anterior cingulate cortex (dACC) of compulsive smartphone users had more neuronal inactivation than the control group.	As to the study, the neural mechanisms involved in interpreting facial emotions may be affected in those who engage in problematic smartphone use.	The research contributes to understanding the neural correlates of excessive smartphone use, emphasizing the role of altered brain activity during facial emotion processing. This information may aid in identifying potential factors contributing to problematic smartphone use.

5. Conclusion

Smartphone addiction goes beyond a societal concern; it involves behavioral addiction linked to neurobiological changes. The findings underscore the complex interactions between neural alterations and smartphone addiction, providing crucial insights into the potential behavioral and cognitive fallout from problematic smartphone use. This review highlights how important it is to have a multimodal approach that takes into account the behavioral and neurological aspects of problematic smartphone use for an individual's overall well-being.

6. Recommendations

Further longitudinal studies are necessary to validate the findings of current research on the brain anatomy and functioning of individuals with PSU. Intervention studies targeting cognitive and emotional regulation, along with those altering brain structure and function, need to be done to reduce harmful effects and encourage healthier technological practices. Ongoing research should explore the complex relationships between smartphone use and neurobiology for tailored interventions and enhanced digital well-being.

7. Limitations

All non-English-language papers were excluded; nonetheless, smartphone addiction has attracted attention from countries in Europe and Asia, and studies may have been published in other languages. As a result, studies carried out in various cultures might be disregarded, which might bias the review findings. Most of the research that met the criteria to be included in this review was carried out in wealthy nations, raising concerns about the generalizability of the applicability of the findings to underdeveloped nations. Finally, many of the results were published with a follow-up of less than a year.

Conflicts of Interest

The authors have no conflicts of interest.

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