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Cognitive functions in Internet addiction – a review

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Summary

The Internet, being generally available, is used by all age groups for professional purposes and also as a form of education and entertainment. It is, however, possible to use the Internet excessively, resulting in an addiction. Internet addiction can be classified as one of the so-called 'behavioral addictions', and until recently it has rarely been addressed in scientific publications. It is therefore important to differentiate between normal and pathological Internet use. This paper presents data on the incidence of Internet addiction and reviews the relevant theoretical models. It also discusses the identification of Internet addiction based on diagnostic criteria suggested by the scientific community. The focus of the article is on executive functioning in this type of addiction. Until recently researchers have put it in the context of a personal, social or emotional area, yet it would seem that cognitive functions play a significant role in explaining the development of addiction, with cognitive control and executive functions being particularly important. In addition, knowledge of these mechanisms can contribute to the development of more adequate forms of prevention and treatment.

Key words: Internet addiction, executive functions, cognitive functions

Introduction

Using the Internet has become a fundamental part of many people's lives. Originally designed as a means of facilitating transfer of textual information, it is now used as a professional tool and a type of entertainment. Without leaving home, one can quickly do shopping, carry out banking operations, run a business, conclude contracts and execute all sorts of transactions – in addition to using the Internet to be socially active and pursue one's interests. Although the Internet offers numerous benefits, its use can have a negative impact on people and an increasingly large number are affected in this way [1]. According to a survey conducted by CBOS (Public Opinion Research Centre) in 2015, the proportion of Internet users in Poland grew from 17% of the population in 2002 to 64% in 2015. In year 2014, 97% of respondents aged 18–24 years and 95%

of respondents aged 25–34 years described themselves as Internet users. The lowest number of Internet users was among people aged 65 years or over – 15% [2]. However, in 2017 the number of people using Internet in Poland increased to 67%. Currently, 100% of people aged 18–24 years, 95% of people aged 25–34 years and 23% of people aged 65 years and over use the Internet [3]. In comparison to year 2015 average time spent online increased from 17 to 20 hours a week for people aged 18–24 years. Moreover, people from this age group are also the most active users of online services and functions [3]. It is possible to become addicted to the Internet generally, but more specific addictions, for instance to online games or social networking sites, are also possible [4, 5].

It should be pointed out that to date most research on Internet addiction has dealt with personal, social or emotional factors [cf. 6–9] and there have been very few studies focused on cognitive functioning in Internet addicts [10]. This is why the main aim of this study was to look at Internet addiction from a cognitive perspective. The potential scope and complexity of such an investigation are vast, so this paper focuses mainly on executive functions, namely the ability of the cognitive system to monitor and control cognitive processes and behavior [11, 12]. The first section of this paper presents data on the spread of addictive Internet use in Poland. Subsequent sections discuss diagnostic criteria and theoretical models of Internet addiction from a cognitive perspective.

The principal objective of this paper is to provide an overview of extant research on the relationship between cognitive functioning, analyzed primarily through functional magnetic resonance imaging (fMRI) and electroencephalography (EEG), and Internet addiction. Having a broader understanding of Internet addicts' cognitive functioning will facilitate understanding of the causes, mechanisms, and effects of this behavioral addiction. The specialist Polish literature lacks a comprehensive study on this topic.

Epidemiology

With its 2012 survey CBOS undertook to study Internet addiction in the Polish population. Approximately 750,000 people are at risk of Internet addiction, i.e., 2.5% of the population. Symptoms were found in approximately 100,000 people, i.e., 0.3% of respondents. It is important to note that as much as two thirds of the population aged under 25 years of age are considered at risk of Internet addiction [13]. According to CBOS survey carried out in 2016 [14], 21% of adolescents show the low/medium risk of Internet addiction and 4% of them show the high risk. This addiction to a greater extent concerns males than females. Furthermore, Pawłowska and Potembska [15] have demonstrated that in adolescents aged 13–24 years, 57% of males and 22% of females were at risk of addiction, while 6.0% and 2.6%, respectively, showed symptoms of addictive Internet use.

Another study reported that 18 to 30% of adolescents aged 11–16 years were at risk, with 9% showing symptoms of addiction [16]. According to Poprawa [17], 13.06% of persons aged 11–24 years are at risk of becoming Internet addicts, whilst 2.08% can be classified as addicts. In the group of people aged 24–65 years, 12.79% are at risk of addiction. Overall 1.9% of respondents revealed symptoms of addiction. Other research showed that 11.3% of boys and 12.8% of girls aged 14–17 years were at risk of pathological Internet use, with 1.8% and 0.8%, respectively, showing symptoms of addiction [18]. Pawłowska et al. [19] imply that 0.45% of adolescents living in the countryside is addicted to Internet and 35.44% is in the risk group. For adolescents living in cities the proportion is 2.06% and 30.18%, respectively.

Krajewska-Kułak et al. [20] observed that 10.3% of nursing students showed symptoms of Internet addiction, with 4.7% suffering from Internet-related withdrawal syndrome. In a study of 536 student, Barłóg [21] showed that 31% of respondents had symptoms of Internet addiction and 51% had average results; Barłóg concluded that this latter group might go on to be at risk of addiction. Less than 20% of the sample showed a low level of problematic Internet use. Higher proportion of male than female students showed addictive Internet use, but this result was not replicated in other studies [22]. Cudo et al. [23] noted that 4.3% of females and 6.3% of males aged 17–30 years exhibited a high level of problematic Internet use. In research by Miedzyński et al. [24] 90% of students declared using the Internet on a daily basis, spending online a total of 21 to 30 hours per week.

On the one hand, the issue of addictive Internet use can be found in various age groups, while on the other hand – researchers point to a high percentage of people at risk of addiction. Considering the epidemiological data as a whole, one can conclude that excessive Internet use is a major social problem that has still not been sufficiently explored and described.

Addiction criteria

Internet addiction has not been recognized as a disorder in the two main international systems for the classification of diseases and mental health problems, namely the ICD-10 and DSM-5. In Poland, the ICD-10 diagnosis system has been in force since 1996 and it was published when access to personal computers and the Internet was not as widespread as it is today. It is likely that the updated version of the ICD, which is currently being developed by the WHO, will include Internet addiction. Although the DSM-5 was published as recently as 2013, it does not recognize Internet addiction as a disorder, however, Section III features the term ‘Internet Gaming Disorder’ and the Manual’s authors stress the need for more comprehensive, clinical studies on the problem as well as basic research [25]. Although the formal classification schemes do not include a nosological unit related to addictive Internet use, researchers have proposed their own diagnostic criteria for these behaviors and

in this work the phenomenon in question will be referred to as ‘Internet addiction’ [cf. 26, 27].

According to Young [28, p. 237] pathological use of the Internet is a “impulse-control disorder that does not involve intoxication, but significantly and obviously impairs the functioning of a person in all spheres of his or her life”. The disorder is diagnosed when 5 out of 8 symptoms have been present during the past year: (1) a strong preoccupation with the Internet, taking the form of thinking constantly about online activity; (2) need to spend increasing amount of time online to achieve satisfaction; (3) repetitive but unsuccessful attempts to control one’s Internet use by reducing it or abstaining altogether; (4) the appearance of marked negative affects, such as depression, irritation etc., when the Internet use is limited; (5) problems controlling the amount of time one spends using the Internet; (6) one’s Internet use produces stress and personal and social problems; (7) using manipulation in relationships in order to hide one’s preoccupation with the Internet; (8) using online activity to regulate one’s emotions; using the Internet as an escape from one’s problems and a method of coping with negative emotional states [28].

Another publication offers slightly different criteria [29]: (1) the need to use the Internet for increasingly longer periods to experience satisfaction; (2) a gradual decrease in satisfaction achieved by using the Internet for a given amount of time; (3) devotion of large amounts of time to online activities; (4) interest in all forms of Internet activity; (5) reducing or completely abandoning other social activities (family, professional, recreational) in order to use the Internet.

According to Beard and Wolf [30], the following symptoms must be present to justify using the term Internet addiction: (1) online activity; (2) the need to spend an increasing amount of time using the Internet to achieve the same level of satisfaction; (3) failed attempts to control one’s Internet use; (4) anxiety and irritation; (5) spending more time online than originally assumed. Woronowicz [31] suggests that Internet addiction can be diagnosed when three of the six following symptoms have occurred during the previous year: (1) a subjective conviction that one lacks control over one’s Internet or computer use; (2) a strong need or compulsion to use the Internet or a computer; (3) attempting to interrupt or limit one’s Internet or computer use results in anxiety, irritability or bad moods which only cease when one resumes one’s former pattern of computer use; (4) increasing neglect of alternative sources of pleasure or past interests; (5) use of the Internet or computers despite an awareness of the potential adverse consequences; (6) needing to spend more and more time on the Internet or using the computer to experience a given level of pleasure or good mood.

Augustynek [32] characterizes Internet addiction syndrome in terms of six symptoms: (1) a strong desire or compulsion to use the Internet; (2) mounting difficulty in refraining from logging on; (3) lack of access to the Internet induces negative mood

symptoms (anxiety, psychomotor agitation, obsessive thinking and fantasizing about the Internet and dampened mood); (4) ever more frequent and longer online sessions, despite their destructive impact on health and social relationships; (5) reduced or no interest in non-computer pastimes, social or occupational activities and reduced ability to relax; (6) spending a lot of time on activity indirectly related to Internet use.

To sum up, it is safe to say that the majority of researchers describing the criteria for Internet addiction liken the phenomenon to addictions to psychoactive substances. In particular, they point to the lack of control over behavior, continuing with the behavior despite its obviously harmful effects, the presence of a strong desire or compulsion to keep performing the problematic behavior and the loss of other interests and limitation on other forms of leisure. Tokunaga and Rains [33] distinguished three approaches to Internet addiction, it may be seen as: (1) behavior on the spectrum of obsessive-compulsive disorders or impulse control disorders; (2) behavior similar to addiction to psychoactive substances; (3) behavior related to deficits in the ability to build and maintain social relationships.

At this point several controversies related to the problem of Internet addiction should be mentioned. One is the question of whether addictive Internet use is a transitory problem or a persistent behavioral disorder [34]. In addition, it is not clear whether the behaviors associated with Internet addiction are a primary or secondary manifestation of other mental disorders, in particular mania, hypomania, depression, addiction to psychoactive substances, sexual dysfunctions, and pathological gambling [34]. There is no coherent and widely-accepted definition of Internet addiction either; this results in use of a variety of theoretical approaches and measurement methods [35, 36]. These factors make it difficult to assess the prevalence of addictive behavior in the population of Internet users.

Selected theoretical models of Internet addiction

The previous section of this paper addressed the issue of diagnostic criteria for Internet addiction. Researchers have not limited themselves to identifying and describing symptoms of pathological Internet use, however, and new theoretical models based on empirical research are being developed to explain how the addiction starts and is maintained, and how it should be treated. Increasingly, researchers are describing the causes and effects of Internet addiction in terms of cognitive function. Hence this section of the article presents the most important theoretical models of Internet addiction, which stress the role of the cognitive system in the etiology and course of pathological Internet use.

Tao et al. [37] proposed a neuropsychological model of Internet addiction. It is based on drawing an analogy between Internet addiction and addiction to a psychoactive substance, and hence underlines the role of the dopaminergic system in the development of addiction. The authors believe that Internet use stimulates the cen-

tral reward system, leading to a pleasant affective state. In the longer term this may generate an urge to spend more time online in order to keep experiencing the same positive affective state. Addiction can be depicted as a circular process in which the following stages can be distinguished: (1) primitive drive associated simultaneously with pleasure-seeking and pain avoidance; a prerequisite for using the Internet; (2) euphoria resulting from central nervous system stimulation associated with using the Internet, which contributes to continuation of Internet-focused behavior; 3) tolerance: increasing use of the Internet raises the pleasure threshold, so that the individual needs to spend more time online to achieve the same effect; (4) an abstinence reaction occurs when Internet use is stopped or reduced, typically manifesting as mood symptoms, insomnia, emotional fluctuations, irritability, etc.; (5) passive coping linked to ineffective behavior based on aggression and escape mechanisms in the face of various challenges and adversities; (6) avalanche effect: repetition of the pathological behavior (Internet use) in order to satisfy the need for pleasure and avoid abstinence reactions; spending time on the Internet is also used as a method of coping with difficult situations [7].

In the cognitive-behavioral model of Internet addiction developed by Davis [38], the mechanisms underlying addictive behaviors are compared with those underlying depression. Problematic behavior is viewed as the outcome of the combination of a number of psychopathological and environmental factors that occur in the context of Internet use. In particular, when Internet use is associated with feelings of wellbeing it can lead to the emergence of maladaptive behavioral patterns. Harmful responses are reinforced by the individual's beliefs and intensifying behaviors and this contributes to the development of addiction. Davis argued [38] that the main cognitive factors in the development and maintenance of Internet addiction are related to one's way of thinking, beliefs, opinions and knowledge of oneself, one's behavior and the surrounding environment.

Davis [38] proposed a distinction between generalized and specific pathological Internet use. In the first case, the user has no clearly defined reason for using the Internet; such cases may be associated with lack of social support, isolation and loneliness. Furthermore, people experiencing such difficulties may be more likely to use instant messaging tools. Internet use may be a way of distracting oneself from one's difficulties or dealing with emotional stress. In contrast, specific pathological Internet use is related to a particular type of online activity (such as gambling, use of pornography, computer games, social networking sites, etc.). Some of the activities and involved content may also be available offline [38].

Brand et al. [39] expanded on the idea proposed by Davis [38] and created a model of functional Internet use as well as models of generalized and specific Internet addiction. The authors point out that in the case of functional Internet use, the Internet is used only as a way of meeting the user's needs and goals and the form his or her

online activity takes and the content sought reflect his or her plans and aspirations. In the case of generalized Internet addiction, they agree with Davis [38] that the main feature is that the user demonstrates a need to be logged on and stay online; the exact forms of activity and content are less important and activity is dispersed across various Internet components. The factors that contribute to generalized addictive Internet use include depression, social anxiety, low self-esteem, procrastination, loneliness, and lack of social support. The individual treats Internet use as a coping mechanism in difficult situations, as a way of controlling negative emotions and running away from everyday life problems.

In specific Internet addiction, the user looks for specific content or activities, such as pornography, online computer games, gambling, etc. and uses specific web applications to obtain content of interest (e.g., pornography) or pursue specific activities (e.g., gambling). What matters is the gratification obtained from contact with a specific form of content or a specific online activity; this reinforces the dysfunctional pattern of use. Depression and social anxiety may be predisposing factors for addiction. Brand et al. also emphasize that users' predispositions may shape the specific pattern of their Internet use, for example, those with higher sexual expectations may be more likely to search for pornographic material. Loss of control, especially when dealing with addictive content, is one of the main symptoms of both forms of Internet addiction [39].

Following further research Brand et al. [40] refined their Internet addiction model, developing what they called the Interaction of Person-Affect-Cognition-Execution (I-PACE) model. They argued that addictive Internet use is a consequence of neurobiological and psychological predisposing factors that are moderated by, amongst other factors, coping style and cognitive errors. The user's cognitive and affective responses to Internet use, combined with reduced cognitive control, are important factors in cognitive dependency on the Internet [40]. A person using a given application gets pleasure from achieving specific goals, which can lead to increased use, because he or she becomes more sensitive to stimuli associated with that Internet application. A reduced ability to constrain his or her reactions to use the application again may also contribute to dependency. Brand et al. [40] showed that as the addiction develops, Internet use becomes a way of compensating for an emerging social deficit and negative emotions, and at the same time perceived gratification is becoming a less and less important incentive for online activity.

These models show that cognitive functioning plays an important role in the etiology and course of Internet addiction. Brand et al. [39] asked what mechanisms underlie continued Internet use in the face of the long-term negative effects of abuse. Specifically they asked whether pathological Internet use is related to inadequate thinking patterns or is a direct response to the stimuli associated with the object of the addiction, such as specific websites, portals, and web applications. In discussing these questions, they argued that the higher cognitive functions, in particular executive

functions, may play an important role in maintaining addiction symptoms. They argued that cognitive control deficits may be of special importance in addictive Internet use. Impaired cognitive control may result in an individual having a limited and over-simplified perception of the situation and difficulties in inhibiting the reaction aimed at Internet use. Studying the neural correlates of Internet addiction may help to determine whether Internet addiction involves generalized cognitive deficits or deficits induced by and specific to exposure to the object of addiction [cf. 10]. Also earlier models of Internet addiction [38, 39] are constantly changing, which results in the role of the cognitive system being increasingly referred to in understanding the mechanisms of addictive Internet use [40].

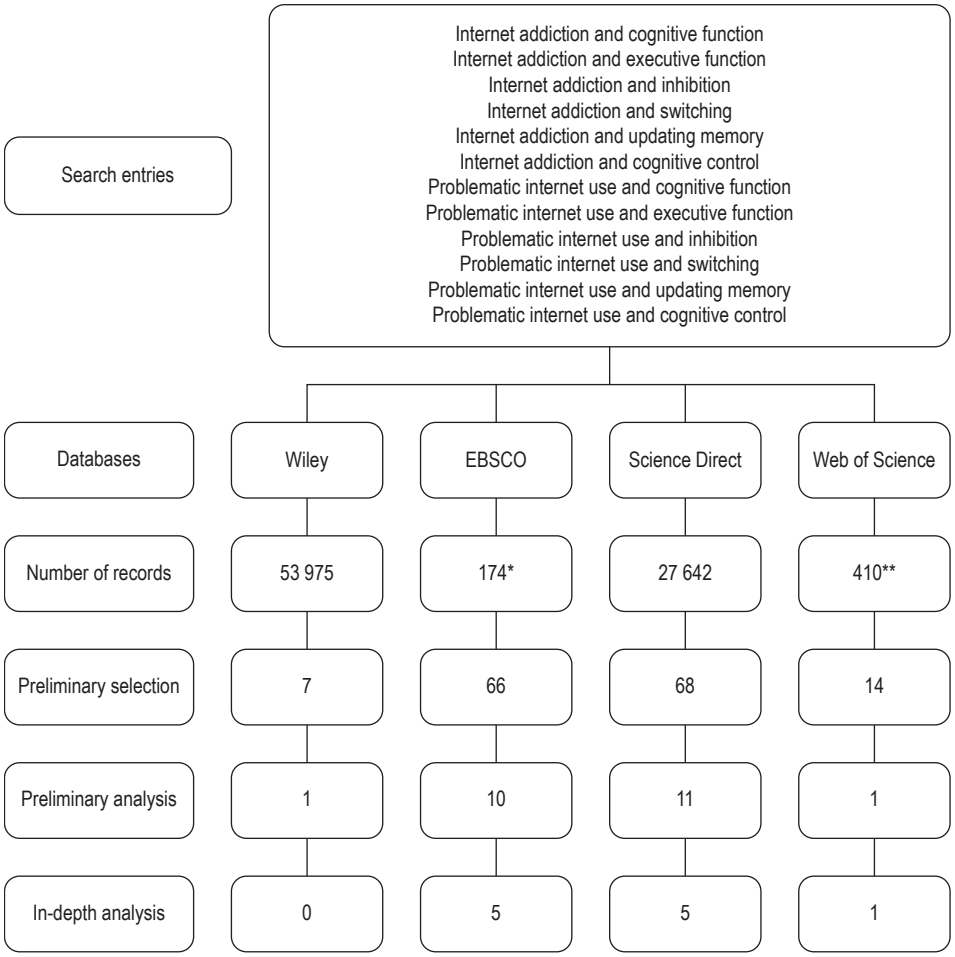
Research on the cognitive functioning of Internet addicts

The definitions of Internet addiction presented thus far indicate the importance of cognitive factors and also highlight neural mechanisms related to addictive behavior. What still needs to be determined is the exact nature of the cognitive processes that play an important role in Internet addiction. First, higher-order processes linked to cognitive control are clearly of primary importance. Cognitive control is the ability to regulate and organize one's own behavior [39, 40] and manifests as flexible adaptation to environmental requirements and the selection of relevant information when competing sources are available. It is related to the reinforcement of behaviors that are consistent with the purpose of behavior as compared to addictive behavior and the dominant/typical reactions [41]. Cognitive control is also defined as the cognitive system's ability to monitor and regulate cognitive processes, and to plan and control their course [12]. Executive functions are non-specific cognitive control processes that are responsible for the most complex, conscious and intelligent responses related to goal-oriented behavior [12, 42].

Miyake et al. [43] studied various tasks commonly considered to be tests of executive functions. Using factor and correlation analyses they demonstrated the existence of three separate executive functions: (a) response inhibition (e.g., Tower of Hanoi and Stop Signal tests); (b) updating and monitoring of incoming information (e.g., Sternberg Test); (c) switching between tasks or states (e.g., Wisconsin Card Sorting Test). Based on the factor analysis they concluded that there was no general factor encompassing performance of these three executive functions. They also observed moderate correlations between the determined constructs. Based on their results they postulated that executive functions include three major processes related to information processing. Some tasks (e.g., generating random intervals) involve all three processes simultaneously, to varying degrees. This review focuses on the role these cognitive processes play in Internet addiction.

Taking into account the above-presented division [43], the literature published before October 2016 in Polish and foreign journals has been reviewed. The authors

searched for research on Internet addiction focused on its impact on cognitive functions, in particular those encompassed by the broad concept of cognitive control. Publications indexed in EBSCO, Science Direct, Web of Science and Wiley databases were searched using the key words 'Internet addiction' and 'problematic Internet use' in conjunction with the following terms: 'cognitive function', 'executive function', 'inhibition', 'switching, 'updating memory' and 'cognitive control'.



* including the Medline and Academic Seach Complete
** databases 'title search'

Figure 1. **Graphic presentation of papers selection**

Figure 1 shows a summary of the records found in each database at various stages of the review. Eleven articles addressing the role of cognitive functions in Internet addiction were selected for further analysis. These articles reported research based on behavioral tests, EEG and fMRI. To ensure transparency and systematize the review only included studies that focused strictly on Internet addiction; studies on addiction to computer games, social networking sites or gambling were not analyzed as these addictions may represent separate problems [cf. 44, 45].

The studies conducted so far indicate that compulsive Internet users show some cognitive deficits (Table 1) compare to people without such behaviors. In particular there are reports of deficits in inhibition [47, 52, 56], decision-making [48, 54], coping with emerging cognitive conflicts [51], working memory [47], task switching [55], and cognitive flexibility [47, 55]. Based on the taxonomy of control processes proposed by Miyake et al. [43] and Chuderski's [57] classification of cognitive control processes, most of these deficits can be related to broadly understand cognitive control system.

Table 1. **The presentation of research on cognitive functions of Internet addicts**

No.	Study	Study group	Type of study	Task	Results
1.	[46]	IAD: 59 Age: M = 15.61 SD=1.73 C: 43 Age: M = 15.35 SD = 1.92	Beh.	Wechsler IQ Test	There were no differences between the IAD and C group on the results of wordless scales of the Wechsler Intelligence Test.
2.	[47]	IAD: 22 Age: M = 28 SD = 7 C: 22 Age: M = 28 SD = 7 AD: 22 Age: M = 30 SD = 6	Beh.	Go/NoGo Task WCST – Wisconsin card sorting test Digit span task	Internet addicts (IAD) compared with the control group (C) disclosed: 1) more false alarms in the Go/ NoGo Task; 2) more errors in the WCST – Wisconsin Card Sorting Test; 3) less correctly reproduced strings of digits; There were no differences between participants addicted to Internet (IAD) and alcohol addicts (AD).

table continued on the next page

3.	[48]	IAD: 52 Age: M = 21.5 SD = 2.3 C: 61 Age: M = 20.7 SD = 2.1	Beh.	Go/NoGo Task Gamblin Task	Internet addicts (IAD) compared with the control group (C) manifested: 1) more correct answers in a situation refrain from reactions in the Go/NoGo Task; 2) lower results in the Gambling Task.
4.	[49]	IAD: 24 Age: M = 16.29 SD = 0.91 C: 26 Age: M = 16.38 SD = 0.75 ADHD: 28 Age: M = 16.29 SD = 0.71 IAD/ADHD: 17 Age: M = 16.14 SD = 0.94	Beh.	Stop Signal Task 2-back Task	IAD and IAD/ADHD groups had lower correctness in the Signal Stop Task in the case of internet-related words compared to internet-unrelated words. In 2-back Task, IAD and IAD/ADHD groups manifested higher correctness and shorter response time in the case of internet-related words compared to internet-unrelated words.
5.	[50]	IAD: 21 Age: M = 23.33 SD = 3.5 C: 20 Age: M = 22.40 SD = 2.33	EEG	Resting state activity	Internet addicts (IAD) compared with the control group (C) manifested: 1) lower power range of beta band; 2) higher power range of gamma band.

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6.	[51]	IAD: 17 Age: M = 21.09 SD = 3.12 C: 20 Age: M = 20.78 SD = 3.47	EEG	Stroop Task	Internet addicts (IAD) compared with the control group (C) disclosed: 1) longer reaction times in incongruent conditions; 2) more response errors in incongruent conditions; 3) lower amplitude of MFN (medial frontal negativity) component in incongruent conditions.
7.	[52]	IAD: 12 Age: M = 20.47 SD = 4.12 C: 12 Age: M = 20.19 SD = 4.47	EEG	Go/NoGo Task	Participants from IAD group compared with the control group (C) manifested: 1) lower amplitude of N2 component in a situation refrain from reactions; 2) higher P3 component in a situation refrain from reactions; 3) longer latency of P3 component in a situation refrain from reactions.
8.	[53]	Subjects:260 Age: M = 19.9 SD = 1.2	fMRI	Resting state activity	There was a positive correlation between the Internet Addiction Test results and activation of the right dorsolateral prefrontal cortex (DLPFC). Moreover, the higher IAT scores are associated with decreased relations between the right dorsolateral prefrontal cortex and the medial prefrontal cortex.
9.	[54]	IAD: 15 Age: M = 22.20 SD = 3.07 C: 15 Age: M = 22.47 SD = 2.53	fMRI	Financial decision-making task	Participants from IAD group compared to the control group (C) showed: 1) more frequent risky decision making; 2) greater activity in the dorsal anterior cingulate cortex (DACC) and the left caudate nucleus; 3) lower activity in the ventrolateral prefrontal cortex.

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10.	[55]	IAD: 15 Age: M = 21.2 SD = 3.2 C: 15 Age: M = 22.1 SD = 3.6	fMRI	Stroop Task	IAD subjects compared to the control group showed: 1) higher superior temporal gyrus activity in switching than in repeating trials; 2) in difficult-to-easy situation: higher brain activity in the insula; 3) in easy-to-difficult situation: higher brain activity in the precuneus.
11.	[56]	IAD: 12 Age: M = 23.6 SD = 3.5 C: 12 Age: M = 24.2 SD = 3.1	fMRI	Stroop Task	Participants from IAD group compared to the control group (C) showed: 1) greater activity in the anterior cingulate cortex; 2) greater activity in the posterior cingulate cortex

IAD – internet addiction disorder group; C– control group; AD – alcohol use disorder group; Beh. – behavioral study; EEG – *electrophysiological study* using EEG; fMRI – neuroimaging studies using fMRI

Dong et al. [51], on the basis of an event-related potential (ERP) study of brain activity during the Stroop test, found that in incoherent conditions Internet addicts had a smaller amplitude of medial frontal negativity (MFN) than individuals who did not exhibit this type of compulsive behavior. The MFN component is an indicator of cognitive conflict detection [58] and is generated in the anterior cingulate cortex [59]. Monitoring of this type of conflict is directly related to cognitive control processes [60]. Dong et al. [56] showed that in incoherent conditions Internet addicts displayed greater activity in the anterior and posterior cingulate cortices when performing the Stroop Test in an fMRI scanner.

Seok et al. [54] reported greater activity in the dorsal part of the anterior cingulate cortex and the left *caudate nucleus*, which are involved in conflict monitoring and rewarding and also showed that reduced ventrolateral prefrontal cortical activity in Internet addicts may be linked to cognitive control deficits. The prefrontal cortex is primarily involved in higher order functions, including cognitive control [61]. Li et al. [53] found a negative correlation between IAT (Internet Addiction Test) scores and the strength of the connection between the medial prefrontal cortex and dorsolateral prefrontal cortex. They suggested that this may be related to a decrease in cognitive control and self-control.

Based on this review of research one can conclude that Internet addicts predominantly suffer from inhibition deficits. Dong et al. [52] observed that reduced ability to detect conflicts is likely to be combined with the need to put more cognitive effort into controlling inhibition processes. The anterior and posterior areas of the cingulate cortex are active during the Stroop Test [56], which may also be indicative of reduced inhibition in the Internet addicts compared to controls. Similar results were obtained by Li et al. [53]. They suggested that the positive correlation between IAT results and right dorsolateral prefrontal cortical activity was indicative of impaired inhibitory control; however, not all studies have confirmed this dependency. Sun et al. [48] showed a greater ability to inhibit the reaction in addicts as compared to the control group. Nie et al. [49] noted that Internet addicts only showed inhibitory deficits in the context of exposure to words related to the Internet. Moreover, Choi et al. [50], when describing differences in beta and gamma signal power between Internet addicts and the control group, indicated that it is coupled with impulsivity levels. Impulsivity may be associated with excessive emotion and with impaired inhibitory control [62]. It has been demonstrated that impulsivity is associated with Internet addiction [63] and with other addictions [64–66]. Impulsivity is also combined with disorders of cognitive flexibility, including stiffness of the reaction despite the changing context of the situation [47] and the difficulty in inhibiting the habitual responses [55]. The different results reported in the above-mentioned studies may be due to the fact that Sun et al. [48] did not control for variance in impulsivity in their research, whereas Nie et al. [49] excluded respondents exhibiting impulsive responses in experimental procedures from further analyses.

Gola [67] showed that what are broadly termed addictive behaviors are associated with several different neural mechanisms: (1) decreased impulse control, (2) increased responsiveness to reward signals and (3) increased sensitivity to anxiety stimuli. The orbital cortex, ventral striatum and nucleus accumbens are involved in learning associations between cues and rewards. Moreover, their activity is linked to motivation to win prizes and learn the various types of promising cues. The dorsolateral prefrontal cortex is responsible for suppressing the activity of the ventral striatum and amygdala. In such a case, deficits in behavioral control may be due to: (1) excessive ventral striatal or amygdalar activity or (2) reduced dorsolateral prefrontal inhibition of ventral striatal and amygdalar activity. Such an approach is also confirmed with regard to Internet addiction.

From this review of literature, it can be concluded that Internet addicts display inhibition deficits [47, 52, 56] that in some cases only become evident when they are in contact with addiction-related stimuli [49]. In this respect, it should be borne in mind that even very similar symptoms may be the derivative of the action of all the mechanisms at the same time, as well as of two or one of them. Gola [67] and noted that both genetic factors (e.g., genetic polymorphisms responsible for expression

of dopaminergic receptors) and environmental factors (e.g., learning to identify the stimuli preceding a reward) may affect the neuronal mechanisms underlying addiction. Also Brand et al. [40] point to similar mechanisms in their model of specific Internet addiction.

Conclusions

Excessive Internet use is a major social and medical challenge. To date most of the research on Internet addiction has looked at personal, social or emotional factors [cf. 6–9] and there have been very few studies focused on the cognitive functioning of Internet addicts [cf. 10], although such research is critical to a full understanding of the psychopathology of this addiction. One can conclude from the review of the available literature that cognitive deficits found in Internet addicts are mostly related to the broad concept of cognitive control, i.e., the ability to control one's responses. There are differences between Internet addicts and symptom-free users at both the behavioral and neuronal level [53, 56]. Moreover, the studies cited above also support Gola's account of addiction [67], which links compulsive behaviors to a limited capacity to inhibition control and to heightened reactivity to cues linked to the object of addiction. Further research into the cognitive causes of Internet addiction is needed to explain the discrepancies in the existing evidence.

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