Review

Neurobiology

Neural Mechanisms of the Reward System and the Cognitive Control System in Internet Addicts

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As a behavioral addiction, Internet addiction has become a global problem that seriously affects people's mental health. According to the neurobiological model of brain development, revealing the neural mechanisms of reward and the cognitive control system of Internet addicts is the key to solving internet addiction. The key to the problem of addiction is also a major issue in psychological research. Behavioral research has explored the characteristics of high reward seeking and low cognitive control in Internet addiction; research on neural mechanisms has revealed that the deficits in reward and cognitive control systems are the root of this behavior. Comparative studies with drug addiction have found that Internet addiction has a unique reward mechanism. These studies have deepened the understanding of the psychological and neural mechanisms of Internet addiction, but there are still differences in the screening and inclusion criteria for Internet addiction. There are some problems that need to be solved urgently, such as science, general classification, lack of causal research, controversial intervention and treatment effects, and loopholes in research paradigms.

Keywords: Internet; Addiction; Adolescent; Reward Seeking; Cognitive Control; Neural Mechanism

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Definition of Internet Addiction

INTERNET addiction was first proposed by the New York psychiatrist Ivan Goldberg in 1995 (1), and Young described internet addiction with reference to the diagnostic model of drug and gambling addiction (2). However, the current international naming of internet addiction is diverse and generally includes two categories: one mainly named "dependence" and the other "pathological computer use" (PCU) or problematic internet use (3). Since there is no consensus on the definition of Internet addiction, to explore the neural mechanisms of reward and the cognitive control systems of Internet addicts, we must first scientifically understand and define Internet addiction.

Studies of Internet addiction is developed from an initial comparison of drug addiction, such as heroin, alcohol, and nicotine, and the concept of Internet addiction is also related to drug addiction. Scholars who hold the above-mentioned first category point out that Internet addiction is different from drug addiction, and it is not an "addiction" in essence. Drug addiction is pro-

duced through long-term drug use, and physiological dependence is its core. Internet addiction is a pure behavioral addiction without any drug intake. The psychological "dependence" or "pathological use" of the Internet is its core. It is not as serious as drug addiction and cannot be called "addiction" (4, 5). Those who fall into the above-mentioned second category point out that Internet addiction, like drug addiction, is essentially an "addictive" behavior. Although Internet addiction belongs to behavioral addiction and drug addiction belongs to substance addiction, their mechanisms are caused by the source of addiction as internet acting on the "reward system" of the brain, resulting in the "reward system" being overly dependent on the network (6, 7).

In view of the above two types of nomenclature, we start from the comparison between Internet addiction and drug addiction and comprehensively believe that Internet addiction is a kind of behavioral addiction demonstrating increased, enhanced tolerance, and clinical features such as withdrawal reactions and mental and physical symptoms. The reasons are as follows:

i. Internet addiction and drug addiction both have the clinical manifestations of addiction. Drug addicts have drug resistance and need to continuously increase the drug dose to achieve the effect that the original lower dose can produce. Once the drug is stopped, it will cause an extremely strong withdrawal syndrome. Internet addicts have a tolerance for Internet use, and their requirements for online time continue to increase. "Tolerance" and "withdrawal" are precisely the two important features of addiction.
ii. Both Internet addiction and drug addiction can cause impairment of behavioral control ability. The core element of addiction is the reduction of behavioral control ability. Drug addiction is a chronic relapse caused by repeated exposure of the body to addictive drugs. Encephalopathy, the main feature of addicts, is compulsive drug use, that is, a loss of control over drug search and intake. Internet addiction is induced by repeated stimulation of the non-material form of the Internet. In the state of long-term obsession, the pleasure of surfing the Internet makes addicts lose control over their own behavior, resulting in a pathological behavior of using the Internet in order to pursue the pleasure brought by the Internet.
iii. Internet addiction and drug addiction have a common neurobiological basis related to the reward circuits. Most of the brain regions involved in the composition of the reward system and the learning and memory system, such as the striatum, the amygdala, the anterior thalamic nucleus, the midbrain periaqueductal gray, and especially the ventral tegmental area, are involved in the pathophysiological structure of drug addiction. The physiological and anatomical structure of internet addiction also involves the ventral tegmental area of the midbrain, the nucleus accumbens, the amygdala, the hypothalamus, the medial prefrontal cortex, and the hippocampus.

Criteria for Measuring and Diagnosing Internet Addiction

i. Tolerance is enhanced, and Internet users have to continuously increase the time spent online to obtain the same satisfaction as before.
ii. Withdrawal symptoms appear, and if they do not use the Internet for a period of time, they will become restless and want to use the Internet irresistibly.
iii. The frequency of surfing the Internet is always higher than planned in advance.
iv. Efforts to shorten the time spent surfing the Internet always ended in failure.
v. Spending a lot of time in communication with the Internet.
vi. Going online has seriously affected social functions such as social interaction, study, and work.
vii. Although aware of the serious problems brought about by going online, they still continue to spend a lot of time on it.

Types of Internet Addiction

Internet game addiction: Internet users are addicted to the virtual world of online games, spending time, energy, and money on their gaming experiences.

Internet relationship addiction: Internet users linger on various chat software, addicted to relationship construction and emotional communication in the online world.

Internet pornography addiction: Internet users are immersed in various pornographic websites and browse pornographic information, pictures, and videos disseminated on the websites.

Information collection addiction: Internet users spend a lot of time browsing various web pages, devoting themselves to finding and collecting too much data, information, or materials on the Internet.

Internet shopping addiction: Internet users are addicted to various online shopping platforms and spend a lot of time and money blindly buying a large number of worthless and practical commodities.

Neural Mechanisms Implications of Reward Seeking and Cognitive Control in Internet Addicts

As a behavioral addiction, Internet addiction, like drug addiction, has become a problem that needs to be paid special attention to. The significance of studying the neural mechanisms of Internet addiction is as follows:

i. Revealing the causes of Internet addiction and formulating prevention and intervention programs have become important issues related to people's physical and mental health. Internet addiction is included in DSM-V as a mental disorder (8). Therefore, to solve Internet addiction, a global mapping of the neural alteration related to addicts' mental health is needed.
ii. Exploring the neural mechanism of Internet addiction can break through the limitations of the phenomenological description of the addiction and promote the solution of Internet addiction. There is a phenomenological description of the causes of Internet addiction in terms of behavior, family, etc., and there is a lack of in-depth research in cognitive neuroscience (9). Internet addicts have abnormalities in neurophysiology, and their formation is mainly caused by psychological factors. Only by exploring the correlation between Internet addiction and specific neural circuits or

nerve centers in the brain can we fundamentally obtain the causal relationship between the psychological characteristics of Internet addicts and neurophysiological mechanisms, so as to better study the psychological and neural mechanisms of dependence and further address the problem.

iii. Studying the neural mechanisms of reward seeking and cognitive control of internet addicts is beneficial to solving the problem of internet addiction. The neurobiological model of brain development points out that various addictive behaviors may be due to the uneven development of the brain reward system and cognitive control system. Based on a large number of neuroimaging studies from adolescent animals and humans, it was found that the reason for adolescents is a high-risk population for various addiction problems is that the brain grows non-linearly during the growth process from children to adults. Compared with children and adults, the bottom-up development of the limbic system related to reward processing is too rapid, and the development of the top-down prefrontal cortex related to cognitive control is relatively delayed (10, 11), which is an important reason for the high incidence of various addiction problems, including Internet addiction in adolescents (**Figure 1**). Starting from the neurobiological model of brain development, the relationship between the brain reward system and the cognitive control system of Internet addicts is revealed; that is, whether the Internet addicts have defects in the reward system or the cognitive control system, or whether the development of the two systems is unbalanced, is the key to solving the problem of Internet addiction, especially for adolescents.

Behaviors of Reward Seeking and Cognitive Control in Internet Addicts

Reward-Seeking Traits of Internet Addicts

Previous behavioral research mainly explored the relationship between Internet addiction and reward seeking from the following three aspects:

i. The role of reward seeking in Internet addiction. Researchers used the Compulsive Internet Use Scale (CIUS) and the Behavioral Approach System Scale (BAS) to find that the desire for rewards can be used as an assessment and predictive indicator of Internet addiction behavior (12), that reward seeking is a risk factor for Internet addiction, and that individuals with higher reward-seeking personality traits are more likely to become Internet addicts.

ii. Internet addicts have higher reward-seeking characteristics. Studies on delay discounting have found that, compared with non-addicts, Internet addicts have a higher rate of delay discounting, and it is more difficult for them to give up small immediate rewards for large long-term benefits. Some used the tridimensional personality questionnaire (TPQ) to investigate the personality characteristics of internet addicts and found that the reward-seeking tendency of college students with internet addiction was lower than that of normal college students and the loss aversion characteristics were not different (13).

iii. The network environment itself promotes reward-seeking behavior, which in turn promotes the emergence of Internet addiction. A questionnaire survey found that the characteristics of the network environment itself, such as virtuality and anonymity, promote people's excessive and unrestricted pursuit of rewards, and the decision-making behavior under the network is more utilitarian (14). Competition and cooperation will be strengthened, and the role they play in the game, the so-called "avatar", will have extraordinary abilities and a highly respected status in the virtual network society as the level increases. The structure of these online games themselves has features that strongly attract gamers to indulge in them (15).

Cognitive Control Characteristics of Internet Addicts

Previous behavioral research mainly explored the relationship between Internet addiction and cognitive control from the following two aspects:

i. The role of cognitive control in Internet addiction using the online cognition scale (OCS), Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (DIM-IV), and Barratt Impulsiveness Scale (BIS-11). One of the key factors of addiction is the reduction of cognitive control in Internet addicts (16).

ii. Decreased cognitive control in Internet addicts. Studies suggested that response inhibition is part of decision-making function, and the measurement of impairment of decision-making function can be interpreted as impairment of response inhibition function (17). In the GoStop task, it was found that the internet-addicted adolescents had a higher error rate in inhibiting the Stop response than healthy adolescents. The score of Young's Internet Addiction Questionnaire was significantly positively correlated with the number of failures to suppress the Stop response and was significantly positively correlated with the score of the Impulsive Questionnaire BIS-11 (18). However, in the go/no-go task, it was found that college students with Internet addiction, there is no difference in the response time and correct rate of college students in the control group in the go condition, and the correct rate of the Internet addicts in the no-go condition is higher (19). The above seemingly contradictory results appear, and it can be speculated that there are at least two possibilities: (i) the two tasks are not specific to the cognitive control tasks related to Internet addiction and do not specifically reflect the deficits of Internet addicts in inhibiting Internet use; (ii) Internet addicts in the GoStop task are adolescents, while Internet addicts in the Go/No-Go task are college students. Compared with adolescent addicts, college students who are Internet addicts have a longer online age, and long-term Internet game play may compensate for or even enhance their inhibition and control abilities.

Neural Mechanisms of Reward and Cognitive Control in Internet Addicts

Studies on the neural mechanisms of drug addiction have revealed a delicate check-and-balance relationship between reward seeking and cognitive control. On the one hand, addictive stimuli enhance striatal activity, which is a typical reward region (20). On the other hand, addictive stimuli elicit stronger re-

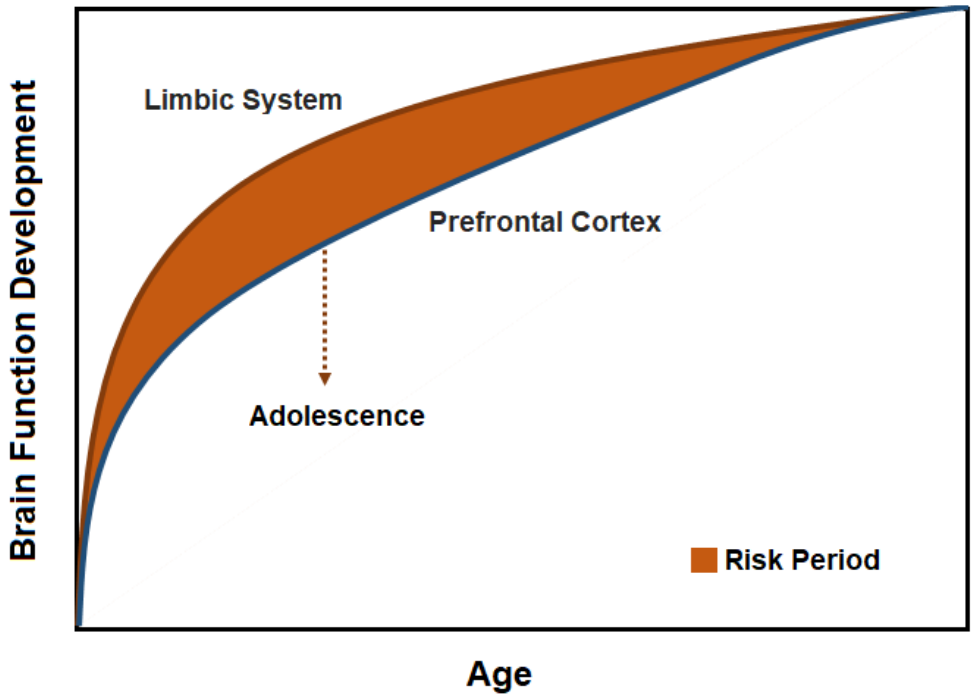

Figure 1. Neurobiological Model of Brain Development.
Compared to children and adults, the imbalance between the development of the subcortical limbic area and the delay in the development of the prefrontal cortex in adolescents is a significant risk factor for addiction among teenagers. The orange curve reflects the rate of functional development of the limbic system in relation to the reward system with age; the blue curve reflects the rate of functional development of the prefrontal cortex in relation to the cognitive control system with age; and the distance between the two curves is proportional to the age difference between the two systems. The gap represents the degree of mismatch between the development of the limbic system and the function of the prefrontal cortex, which is predictive of the risk level of various behaviors such as addiction.

ward-seeking behaviors, dysfunctioning the frontal cortex responsible for cognitive control (21). Internet addiction may share a similar neural basis with other drug addictions and behavioral addictions (22).

The Reward System of Internet Addicts

The reward system is an important neurobiological basis of Internet addiction. Studies have shown that striatum and midbrain regions related to reward include dopamine neurons in the entire striatum and substantia nigra. First, the striatum will receive substantial dopaminergic input from the orbitofrontal cortex and anterior cingulate cortex, as well as from the midbrain. The striatum then projects information to the ventral pallidum and ventral dorsal tegmental area/substantia nigra, and projected to the prefrontal cortex through the dorsal medial nucleus of the thalamus, forming a loop. This loop is an integral part of the cortex-basal ganglia system. In addition, other brain structures, including the amygdala, hippocampus, and lateral habenular nucleus (lateral habenular nucleus), and specific brainstem structures like the pedunculopontine nucleus and raphe nucleus, are also important components of the regulation of the reward circuit (23).

A study of gene polymorphisms found that those who carry TaqA1 alleles and COMT low activity alleles have defects in their dopaminergic system and are more likely to develop Internet addiction (24, 25). This shows that Internet addicts have specific neurobiological characteristics; therefore, the treatment of internet addiction requires not only psychological counseling and behavior modification but also specific pharmacological treatment. As a genetic study, the sample size of this study is relatively small; it is not possible to confirm the role of dopamine gene changes in Internet addicts in psychopathology. Another study of gene polymorphisms found that, compared with healthy people, internet addicts have a higher frequency of the serotonin transporter gene, which is associated with higher loss avoidance scores (26).

Neuroimaging research using a variety of techniques has consistently found that the reward system of Internet addicts is abnormal. Single photon emission computed tomography (SPECT) research has found that the dopamine transporter (DAT)

of Internet addicts were significantly reduced (27), so it is believed that Internet addiction may have similar neurobiological variations to drug addiction.

Morphometric studies have found that Internet addicts have decreased gray matter density in areas such as the left anterior cingulate cortex, left posterior cingulate cortex, left brain insula, and left lingual gyrus, which are associated with emotional behavior regulation (28). Changes in the brain structure of addicts may be the pathogenesis of Internet addiction. Diffusion-tensor imaging (DTI) found that the fractional anisotropy value (FA) increased, while the white matter FA value of the right parahippocampal gyrus decreased, and the changes in gray matter and white matter volume were significantly correlated with the addiction time of Internet addicts (29, 30). This indicates that the brain microstructure of internet addiction has changed.

A study using positron-emission tomography (PET) found that raclopride binding to D2 receptors in the striatum was reduced during video game play compared to when people were resting (31). This shows that the internet game has changed the neurobiochemical level of the brain. Another study found that, compared with the healthy group, apraclonidine bound to the D2 receptor in the striatum of the internet addiction group, and the degree of reduction is positively correlated with the degree of Internet addiction (32), which confirms the changes in the neurobiochemical levels of Internet addicts, but it still does not confirm the causal relationship between Internet addiction and changes in neurobiochemical levels.

A functional magnetic resonance imaging (fMRI) study found that neuronal circuits involved in reward and addiction were involved when people were playing a "spatial scramble" game compared to a control task, such as, there was greater activation in the insula, nucleus accumbens, dorsolateral prefrontal cortex, and orbitofrontal cortex (33). This shows that a real game can indeed change the brain through behavior. The study also found that during the game, the mesolimbic the activation and functional connectivity of the dopamine system, the desire to win, and the acquisition of rewards are higher than those of women. These results can help people understand, from the perspective of neuroimaging, why people prefer to play games and are more prone to Internet addiction. Another fMRI study asked college students to play online games for 6 consecutive weeks and performed functional imaging scans on the brains of college students before and after playing games for 6 weeks. Comparing the brain function imaging before and after the measurement, it was found that after 6 weeks, the development of the Internet addicted individuals showed greater activation in both the anterior cingulate cortex and orbitofrontal cortex when viewing Internet game cues, whereas brain activation patterns were unchanged in gamers without Internet addiction (34). This longitudinal study, from causal attribution has been confirmed that Internet addiction can change the activation pattern of the brain. The study also found that the self-reported desire to play Internet games is positively correlated with the activation of the prefrontal cortex. This shows that both Internet addicts and individuals with addiction characteristics change the activation pattern of the brain's reward network, and the change in the activation of the prefrontal cortex may be a sign of the early onset of Internet addiction (34). The gambling task of guessing cards found that, compared with the healthy group, in the winning trials, the activation of the orbitofrontal cortex related to reward processing is stronger in Internet addicts, and it is positively correlated with the degree of Internet addiction; in loss trials, the activation of the anterior cingulate cortex related to loss processing in Internet addicts is lower (35). This tells that Internet addicts not only increase their sensitivity to rewards but also reduce their sensitivity to losses. Abnormalities in activation, using the method of regional homogeneity (ReHo), it was found that, compared with the normal control group, the activation of reward networks such as the hippocampus in Internet addicts increased (36). This indicates that Internet addiction alters the brain's reward circuitry. However, because assessments of brain region homogeneity were obtained in the resting state, it is also impossible to infer a causal relationship between changes in brain activation and Internet addiction.

The Cognitive Control System of Internet Addicts

Studies have found that the cognitive control function of internet addicts is impaired, and the brain areas related to cognitive control function are abnormal. However, there are only a small number of event-related potential (ERP) studies and brain imaging studies.

Some ERP studies using go/no-go tasks, or color-word Stroop tasks found that Internet addicts have reduced cognitive control ability. In some go/no-go tasks, compared with healthy people, Internet addicts in under the no-go condition, the amplitude of the N2 component of the frontal area and the central area of the representational conflict monitoring decreased, the amplitude of the P300 of the representational response evaluation increased, and the peak latency was prolonged (37). This demonstrates that Internet addicts have more inefficient information processing and poorer impulse control, requiring more cognitive resources and voluntary effort for response evaluation and inhibitory control. There is also a go/no-go task study examining error-related negativity (ERN) in Internet addicts. It was found that Internet addicts had lower ERN amplitude, higher self-reported impulsiveness, and worse performance of behavioral inhibitory control (38). In the color-word Stroop task, compared with controls, internet addicts responded more slowly in the congruent condition and had more false positives and reduced skewness of the midfrontal negativity (MFN) (39, 40). The standard auditory oddball for measuring cognitive control the task found that the latency of P300 related to cognitive processing was prolonged in Internet addicts, but after 3 months of cognitive-behavioral treatment, the latency of P300 was significantly shortened (41). This longitudinal study shows that Internet addicts have cognitive control deficits that can be corrected with cognitive-behavioral therapy.

PET studies have found that the bilateral postcentral gyrus, left precentral gyrus, and bilateral occipital regions associated with cognitive control in adolescent Internet addicts have decreased glucose metabolism activity (42). This indicates that there is a deficit in the cognitive control ability of adolescents with Internet addiction.

Morphometric neuroimaging studies found that Internet

addicts had reduced gray matter density in the left cingulate and left thalamus, which are involved in regulating addictive behaviors and focused attention (43). Diffusion tensor imaging studies have found that compared with healthy adolescents, the left side of the brain of adolescents with Internet addiction, some white matter fiber tracts (including the corpus callosum, external capsule, internal capsule, corona radiata, cingulate zone, etc.) are damaged, and these brain regions are mainly responsible for the executive function of the brain (44). It can be speculated that the brains of adolescents with internet addiction are impaired for its executive function, but the causal relationship between Internet addiction and brain area damage is still unable to be drawn.

Commonalities and Differences between Internet Addiction and Drug Addiction in Reward Seeking and Cognitive Control

Internet addicts and drug addicts also have defects in the reward system and cognitive control system, which determines the commonality between the two.

i. Compared with healthy people, Internet addicts and drug addicts have higher scores on impulsivity and sensation-seeking items. Internet addicts are addicted to the pleasure of surfing the Internet, making their online behavior uncontrollable without drug effects, and drug addicts also found it is difficult to resist the temptation of drinking or taking drugs. This shows that Internet addicts are similar to drug addicts: they both seek the pleasure brought by the Internet or addictive drugs excessively, and it is difficult to control their addictive behavior.
ii. The delay discount in the task, Internet addicts and drug addicts have higher delayed discounting rates than the control group, and both give up future large rewards in order to obtain immediate small rewards. Internet addiction and drug addiction share neuronal circuits. Studies have found that brain regions activated by game cues in Internet addicts, including the orbitofrontal cortex, dorsolateral prefrontal cortex, anterior cingulate gyrus, and nucleus accumbens, are associated with drug addiction. The brain area activated by internet cues is the same as that of the drug cues. Some addiction treatments have found that naltrexone, as an antagonist of opioid receptors, can treat alcohol and opiate addictions, and it can also treat Internet addiction in clinical practice (45). This shows that opioid receptors play a similar role in the treatment of behavioral addiction and drug addiction through the mesolimbic dopaminergic pathway.

Internet addiction is different from drug addiction, and there must be some differences in the neural mechanisms of reward seeking and cognitive control, which reflect the uniqueness of Internet addiction itself.

i. Internet addiction has no defects in reward seeking or cognitive control. Affected by any drug ingestion, it is a purely mental addiction, whereas drug addiction, with deficits in reward seeking and cognitive control affected by drug ingestion, is an addiction with mixed psychic and drug factors.
ii. In the dimension of loss aversion, compared with healthy people, Internet addicts had higher scores or no difference, while drug addicts had loss aversion in the dimension of reward. Neuroimaging data have shown that internet addicts had no deficits in the reward risk assessment task, whereas drug addicts performed worse on that. This means that Internet addicts are able to notice potential losses, while drug addicts focus only on immediate rewards and fail to notice potential losses.

Perspective and Conclusion

It is necessary to formulate scientific screening and inclusion criteria for internet addiction. So far, it is difficult to achieve uniformity, even if some standardized criteria are formed. Addiction diagnostic criteria require researchers to pay attention to absorbing the scientific components of the previous criteria and to summarize them systematically.

It is necessary to refine the subtypes of Internet addiction. Based on previous research on behavior and neural mechanisms, it can be seen that Internet addiction behavior may be related to the defects of the brain reward system and the defect of the cognitive control system, or the defects of the unbalanced development of the reward system and the cognitive control system. According to the defects of different brain systems, Internet addicts can be further divided into three subtypes: (i) those with reward control system defects, (ii) those with cognitive system defects, and (iii) those with common defects in both the reward system and cognitive control. When carrying out various prevention and treatment programs related to Internet addiction, it is necessary to target different Internet addiction subtypes and carry out targeted interventions.

Causal studies on the neural mechanisms of Internet addiction need to be strengthened. Most of the current studies on Internet addiction focus on comparative studies between Internet addicts and the controls. Although studies have shown that compared with healthy people, Internet addicts showed changes in their reward and cognitive control systems, but whether Internet addiction leads to brain changes or whether brain changes lead to Internet addictive behaviors has not yet been determined. Longitudinal follow-up studies, including predicting and tracking people's Internet addiction behavior in real-world game scenarios and follow-up studies on the relapse of Internet addicts, are worth exploring in the future and will more effectively reveal the underlying mechanisms of Internet addiction.

The effectiveness and necessity of Internet addiction intervention and treatment need to be confirmed. According to the neurobiological model of brain development, Internet addiction seems to be a product of the brain development process. In other words, as the individual brain development matures, the Internet addiction behavior will probably be self-healing (46, 47). However, how to eliminate doubts and debates and find a scientifically unified indicator for predicting Internet addiction and how to evaluate the effect of treatment more scientifically are issues worth being dug into and explored in the future.

It is necessary to innovate the research paradigm on Internet addiction. From the perspective of research paradigm, most of the current research paradigms of Internet addiction reward and cognitive control are some classic paradigms, such as the simple decision task of research reward and the study of cognition. These paradigms are only for general reward evaluation and cognitive control, so whether they can sensitively capture the specificity of internet addiction in reward and cognitive

control is unclear. Although there are some studies using the cue-reactivity paradigm related to online games, there is a world of difference between just watching some online game-related pictures and fighting in an online game. At the same time, the Internet is only a medium, and Internet addicts do not attribute Internet addiction to the Internet itself. In fact, some potential personality traits or problem behaviors may be the potential causes.■

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