A New Network-Theory-Based Perspective on Substance Addiction: Postprint

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Date: 2022-07-28T00:00:00+00:00

Abstract

Substance addiction is a complex phenomenon involving multiple factors such as physiological, psychological, and environmental elements; however, current explanations grounded in biological reductionism have impeded holistic understanding of substance addiction phenomena and rehabilitation research. Network theory, which focuses on feedback loops formed through interactions among psychopathological variables, offers a novel theoretical framework for studying substance addiction from a holistic perspective. The application of network theory to substance addiction research will facilitate: (1) understanding the interrelationships and mutual influences among symptoms; (2) comprehending the holistic and systematic dynamic evolution of symptom networks; and (3) integrating multi-level and multi-layer factors into a unified theoretical framework. Understanding substance addiction from a network theory perspective will also provide theoretical support for future interventions and treatments. Currently, network theory remains at the stage of verbal models, and future research needs to develop more specific and verifiable statistical models to enhance understanding of substance addiction mechanisms and more effectively promote treatment and recovery.

Full Text

Preamble

A New Perspective on Substance Addiction Based on Network Theory

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Abstract

Substance addiction is a complex phenomenon involving multiple factors spanning physiological, psychological, and environmental domains. However, current explanations grounded in biological reductionism have hindered a holistic understanding of addiction and research into effective recovery. Network theory, which focuses on feedback loops formed by interactions among variables underlying psychological disorders, offers a new theoretical framework for studying substance addiction from an integrative perspective. Applying network theory to substance addiction research can facilitate: (1) understanding the interrelationships and mutual influences among symptoms; (2) comprehending the holistic and systematic dynamic changes in symptom networks; and (3) integrating multi-level and multi-factor influences into a unified theoretical framework. This network perspective also provides theoretical support for future interventions and treatments. Currently, network theory remains at the verbal model stage, and future work must develop more specific, testable statistical models to improve understanding of addiction mechanisms and advance treatment and recovery efforts more effectively.

Keywords: substance addiction; network theory; biological reductionism; dynamical system

Substance addiction refers to the loss of control over substance use, compulsive drug-seeking behavior, and continued use despite adverse consequences [?]. From a legal standpoint, addictive substances are typically categorized as illegal drugs (e.g., heroin, methamphetamine, cocaine, marijuana) and legal addictive substances (e.g., cigarettes, alcohol). A community-based study in China reported that the lifetime prevalence of any substance addiction (including alcohol and illegal drugs) reached 5.58% [?]. Substance addiction and related psychological disorders have become one of the most prevalent and serious public health problems worldwide [?]. The social problems associated with illegal drug use are particularly severe, creating a cascade of interconnected issues including HIV/AIDS, theft, violent crime, and drug-impaired driving that pose serious threats to public safety. According to the 2019 China Drug Situation Report released by the National Narcotics Control Commission in 2020, by the end of 2019, the number of registered drug users in China had reached 2.14 million, accounting for 0.16% of the total population. In 2019 alone, authorities apprehended 617,000 drug users, with 394,000 being repeat offenders, indicating a persistently high relapse rate [?]. This represents a significant risk to individual physical and mental health as well as to national and social stability.

The concept of "addiction" has been recognized since our ancestors discovered that fermented fruits and grains could induce intoxication [?]. Over time, understanding of addiction has evolved. In 1964, some psychiatrists proposed replacing "addiction" with the seemingly more neutral term "dependence" [?]. However, “dependence” is often associated with drug tolerance and withdrawal syndromes, reflecting primarily the physiological maladaptation caused by drugs. This does not align with the compulsive nature of addiction and the impulsive behavior despite consequences. “Substance dependence” fails to adequately distinguish between true addicts and patients who experience withdrawal symptoms without drug abuse behavior [?]. Although the *Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition* (DSM-5) no longer distinguishes between substance dependence and substance abuse, collectively terming them substance use disorders [?], these concepts are relatively recent and have specific connotations in psychiatry, predominantly understanding addiction through a biomedical model. The DSM-5 assumes that substance use disorders represent biological entities in disease taxonomy and aims to define and identify one or more common underlying physiological causes for different symptoms [?]. However, the effectiveness of current mainstream medical model treatments for substance addiction remains unsatisfactory. According to available data, even in Western countries with well-developed treatment systems, 71% of opioid addicts relapse within two months of treatment [?]. [?] found that relapse rates for nicotine, heroin, and alcohol within one year of abstinence are similar, ranging from 80% to 95%. In China, the relapse rate for heroin addicts exceeds 93.5% within six months [?]. Furthermore, outside medical treatment models, many drug addicts achieve spontaneous recovery without any treatment [?]. Some addicts achieve positive recovery outcomes simply through changes in belief. For instance, research has found that addicts who view themselves as having unhealthy habits recover more easily than those who consider themselves chronically ill [?].

In recent years, the biomedical model that seeks biological causes for substance addiction and other psychological disorders has faced increasing skepticism and challenge. Some psychiatrists have proposed that psychological disorders result from interactions among symptoms rather than from common physiological causes [?, ?]. Driven by this perspective, network theory has gradually attracted researchers’ attention, positing that the essence of psychological disorders is a complex network system formed by interactions among symptoms. Due to feedback loops among symptoms, the symptom system remains in a state of dynamic self-maintenance, making spontaneous recovery difficult [?, ?].

Currently, various network analysis models have been developed based on network theory concepts (see [?]) and applied to different psychological disorder studies [?], such as major depressive disorder [?, ?, ?], post-traumatic stress disorder [?, ?, ?], and eating disorders [?]. [?] also first applied network analysis models to substance abuse, offering new understanding of addiction disorders from a symptom network perspective. As a new perspective on mental illness, network theory not only constructs visualizable symptom networks through network analysis models but more importantly helps us re-examine substance addiction phenomena involving different levels of factors from physiology to psychology and culture [?, ?]. Integrating different levels of factors into a network framework can provide richer information and tools for understanding addiction development processes and interventions. However, it is worth noting that the purpose of network analysis models is to reveal connection patterns among symptoms and provide evidence for symptom interactions. As a tool, the model itself does not spontaneously generate substantive theory to explain the nature of psychological disorders. Without theoretical guidance behind the model, merely using network analysis models to change existing data modeling forms may lead to limited interpretation of these connection patterns. This article first reviews the current mainstream biological reductionist perspective on substance addiction and points out its limitations; second, it introduces the characteristics and advantages of network theory; finally, it discusses the application of network theory to substance addiction. We hope this new perspective from network theory can provide reference and inspiration for future research directions in substance addiction.

2. Substance Addiction Research Based on Biological Reductionism

The current mainstream view holds that substance addiction is a chronic brain disease in which "patients" exhibit repeated drug use behaviors due to drug effects on the brain [?, ?, ?]. For example, the National Institute on Drug Abuse (NIDA) defines substance addiction as a chronic, relapsing brain disease that causes compulsive drug use. Numerous research findings from NIDA, the American Medical Association (AMA), the National Institutes of Health (NIH), and the American Society of Addiction Medicine (ASAM) support this view [?], which holds that substance addiction is related to damage to neural synapses or brain circuits, particularly dysregulation of the mesolimbic dopamine system. Additional evidence comes from early animal experiments, which found that animals exposed to heroin, amphetamine, and morphine showed changes in dopamine metabolism and alterations in brain synaptic structure, consistent with changes in striatal dopamine activity in humans after drug use [?, ?]. Under prolonged drug exposure, the dorsolateral prefrontal cortex (DLPFC), which is involved in reasoning, planning, and self-control, gradually loses functional connectivity with the striatum, amygdala, and other motivation-related regions [?, ?]. Some researchers believe this is the fundamental reason why substance addicts repeatedly exhibit "crazy" drug-seeking behavior—their brains have been "hijacked" by substances [?]. These research findings seem to support substance addiction as a chronic brain disease with typical physiological characteristics. Some researchers believe that in the near future, better equipment and methods will enable precise localization of substance addiction to specific lesion areas in the brain [?].

Although current research in cognitive neuroscience and biological genetics has provided a foundation for understanding substance addiction, as [?] notes, after decades of effort, the genetic, metabolic, and cellular characteristics of almost all psychological disorders remain largely a mystery. Regarding addiction research, findings from cognitive neuroscience on dopamine, neurotransmitters, and genes have not yet enabled us to equate substance addiction with pure physiological diseases (such as heart disease or cancer) and explain and predict it using a single biological theory [?].

The reason why biological reductionist explanations have long occupied a dominant position in traditional substance addiction research is that evidence primarily comes from three aspects: first, dopamine uptake in the mesolimbic system (related to reward) increases dramatically when addicts encounter drug-related cues [?]; second, after long-term drug use, dopamine receptors (such as D2 and D3 receptors) in addicts show reduced levels in response to non-drug activities, leading to a blunted dopamine system; and third, changes in the prefrontal cortex occur, such as reduced synaptic density [?] and weakened functional connectivity with the striatum, impairing addicts' control abilities and increasing the likelihood of use in high-risk situations [?]. However, these do not represent the complete picture of addiction phenomena. Individual behavioral performance in different environments can also affect physiological structures. For example, long-term training leads to structural changes in the hippocampus of London taxi drivers [?], and high-frequency acrobatic training affects performers' gray matter density [?]. Brain changes can influence individual addiction symptoms and lead to broader symptom manifestations [?]; conversely, individuals lacking social support who experience persistent reduction in social activities become more dependent on drug effects, exacerbating drug-induced brain changes [?, ?]. Viewing substance addiction as a brain disease essentially places biological-level explanations in a primary or even exclusive position. This explanation is premised on biological reductionism, which holds that higher-level conceptual terms can be explained and defined through lower-level concepts. For example, temperature, as a higher-level abstract concept, can be reduced to and explained by the average kinetic energy of gas molecules at a lower level.

Biological reductionist explanations are not uncommon in psychiatry and have remained the mainstream paradigm for understanding mental illness in recent decades [?]. Although addiction phenomena show clear biological traces, using biological reductionist assumptions to explain substance addiction may be inadequate for two main reasons:

First, current substance addiction diagnoses rely on symptom descriptions rather than biological markers. This means addiction diagnosis always precedes neurophysiological explanations. It is rare for individuals to be diagnosed with addiction disorders solely based on neurotransmitter or brain circuit abnormalities. In other words, lower-level biological explanations depend on higher-level symptom descriptions, whereas average kinetic energy does not depend on the concept of temperature for its existence—a fundamental distinction from substance addiction. Many physiological mechanisms found to be related to addiction also exist in other normal phenomena. For example, changes in the mesolimbic dopamine system in addicts in response to drug cues are similar to those observed in humans during partner pursuit, shopping, wealth acquisition, and religious activities [?, ?, ?], and are not unique to substance addiction.

Second, causal evidence between substance addiction and physiological factors is ambiguous. For instance, the decline in dopamine receptor levels (such as D2 and D3 receptors) is attributed to long-term drug use and considered a cause of addicts' desensitization and blunting to non-drug cues. However, other research shows that poverty, trauma, and decreased social status also reduce D2 and D3 dopamine receptor levels. In other words, addicts facing adversity also exhibit abnormal dopamine receptor levels, which reduces their need for activities other than drugs and maintains drug use [?].

Furthermore, for physiological diseases such as AIDS, individuals can be diagnosed as HIV carriers based on viral infection even without symptoms. Similarly, according to the biological reductionist view, if substance addiction is considered merely a physiological disease rooted in the brain, it should be detectable through some biomarker even when addicts do not exhibit drug abuse behaviors (i.e., symptom manifestations). However, the current reality is that addiction cannot be diagnosed separately from its symptom manifestations—there are no substance addicts without drug abuse behaviors [?].

Nevertheless, most addiction researchers still operate under biological reductionist assumptions, aiming to find "biomarkers" [?]. However, some researchers recognize the complexity of substance addiction and have begun exploring the influences of physiological, psychological, and environmental factors on addiction [?, ?, ?]. Although the latter approach uses a holistic view to construct theory, it merely shifts from a single latent variable (brain disease) to multiple latent variables (physiological, psychological, and social factors) for explanation. It has not yet studied the interactions among addicts' symptoms as an important phenomenon, neglecting the complexity and systematic nature of addiction. Based on the complexity of psychological disorders, [?] argue that psychological disorders are not ontologically any type of essentialism (including biological essentialism). Instead, they are clusters formed by different mechanisms, similar to explanations of species development in biology [?]. For complex phenomena like substance addiction, simplified explanatory approaches based on biological reductionism are often ineffective [?], resulting in persistently high relapse rates and urgently requiring new theories to provide an integrated framework for interactions among factors at different levels.

3. Basic Concepts and Analytical Models of Network Theory

Recently, one of the major theoretical achievements in psychiatry has been moving away from single-factor biological reductionist explanations of psychological disorders [?, ?], generating new perspectives and viewpoints: (1) psychological disorders have complex multi-causal relationships; (2) maintenance mechanisms of psychological disorders cross different diagnostic frameworks; and (3) psychological disorders require diversified explanations [?]. Network theory represents one such new perspective. It no longer assumes that substance addiction has one (or multiple) underlying common causes but instead constructs complex network systems through mutual influences among important nodes (such as core symptoms of substance addiction and environmental factors) [?]. Since nodes in the network are no longer independent but have interacting causal relationships, network theory effectively addresses the shortcomings of biological reductionism in explaining substance addiction phenomena [?].

The complex systems perspective embedded in network theory provides new analytical perspectives and integration approaches for substance addiction while offering direction for transforming verbal theory into formal theory. The purpose of verbal theory is to explain a phenomenon in real life, whereas formal theory models, verifies, and generalizes the phenomenon through empirical methods [?]. Network theory currently remains a verbal theory, while network analysis models serve as quantitative tools to implement network theory, primarily applying graph theory from mathematics to network theory and establishing corresponding statistical models. Typically, network analysis models include nodes and edges. In classic social network analysis, nodes are individual persons, and edges are interactions between individuals [?, ?, ?].

Over the past decade, network analysis models have developed rapidly and been applied in psychiatry, clinical psychology, social psychology, and personality psychology (see [?]). However, the rapid development of network analysis models does not directly reflect the difference between network theory and traditional biological reductionist thinking. As mentioned earlier, models only serve as tools to better implement network theory and do not advance the theory itself. Network analysis models and traditional statistical models are not mutually exclusive; they have commonalities. For example, in statistical results, the Rasch model can be equivalent to the Curie-Weiss model (a special case of the Ising model for dichotomous variables in network analysis) [?]. Similarly, when exploring questionnaire data structures, network analysis models also share similarities with factor analysis—factors can also cluster in networks to reflect questionnaire structure [?]. Network theory is not incompatible with research on addiction physiological mechanisms but no longer considers physiological mechanisms as occupying a primary explanatory position in the addiction network system. Instead, it places them on the same level as other psychological or environmental factors that jointly determine the development of the entire symptom system [?]. Under the guidance of network theory, substance addiction models constructed from factors at different levels can directly visualize the associations and structures among observed variables, which is difficult to achieve with latent variable models based on biological reductionism. Specifically, applying network theory to substance addiction research has four main advantages:

First, it focuses on symptoms and the connections between them. It is no longer limited by the common cause assumption in biomedical reductionism that neurobiological substrates are the root cause of a series of symptoms. It shifts the focus of substance addiction research from searching for essences on a physiological basis to studying the role of physiological processes in network structures.

Second, current diagnoses are typically based on total scale scores or symptom counts, meaning not every individual diagnosed with substance addiction has the same symptom profile. Traditional diagnostic approaches lose much important information [?]. Network theory's focus on symptoms and their interconnections can provide dynamic changes of each symptom in the network at different time points, offering theoretical support for assessing individual psychological status and developing personalized intervention plans.

Third, complex network systems formed by relationships among variables have characteristics of stability and self-reinforcement. Addicts' symptoms persist even after external stressors disappear, which not only aligns with network theory assumptions but also matches current clinical observations [?, ?]. In other words, once individual symptom networks form mature causal feedback loops, external factors are no longer necessary drivers of symptom development [?]. This self-reinforcing state of symptom networks is similar to self-organization processes in complex ecosystems [?, ?], providing theoretical support for studying the complex dynamics of substance addiction.

Finally, network theory no longer assumes priority among different causal factors, facilitating the integration of physiological, psychological, and environmental factors at different levels into the model. Networks composed of different nodes may have multi-level feedback relationships, and their integration can provide a more comprehensive understanding of the complexity of substance addiction' s internal mechanisms.

4.1 Static Symptom Network Analysis Models

The DSM-5 assumes that substance use disorders have some underlying common cause, so the presence of any two of 11 symptom criteria warrants diagnosis. A thought-provoking question arises: if individuals A and B are diagnosed with the same psychological disorder through completely different combinations of two symptoms, psychiatrists using the DSM system or total scale scores will have difficulty detecting differences between the two individuals. This may explain why even addicts who have undergone two years of compulsory detoxification still have high relapse probabilities after leaving treatment facilities when drug effects have diminished. To enable researchers, psychiatrists, and related professionals to diagnose, intervene, and treat based on individual characteristics, it is necessary to conduct personalized examinations of symptoms themselves and their network architecture.

In fact, the diagnostic criteria in DSM-5 are not completely independent; psychological disorder symptom descriptions cluster together precisely because they implicitly contain causal connections. Many criteria require psychiatrists or substance addicts themselves to make causal inferences during diagnosis. For example, within a single criterion, "repeated use of a substance" leads to "failure to fulfill major role obligations at work, school, or home." Additionally, criteria conform to causal logic: for instance, increased "tolerance" means individuals need larger doses, leading to "spending a great deal of time obtaining the substance" ; "withdrawal symptoms" and "craving" have long been considered related to "high-risk use" and "social dysfunction behaviors" such as crime, needle sharing, and prostitution [?, ?]. The natural internal connections among symptoms not only align with network theory assumptions but also facilitate the construction of network analysis models. Using symptoms as nodes can more clearly reveal their interaction patterns, which is epistemologically fundamentally different from traditional latent variable models based on biological reductionism.

Although selecting symptoms for inclusion in network analysis models should be based on research questions and hypotheses, choosing variables that can represent the essence of psychological disorders, selecting from existing diagnostic manual symptoms is a convenient way to initially implement network theory [?]. In the DSM system, symptom criteria for clinical diagnosis come from expert 论证 and practical testing in the field, with each symptom having good representativeness. Existing substance addiction symptom network research results also indicate that DSM symptoms have certain intercorrelations in network analysis models, though some symptoms show weaker interconnections, such as "physical or psychological problems,""difficulty quitting,"and the "legal problems"criterion removed in DSM-5, which all show low scores on multiple connectivity indicators in network analysis models [?]. To more clearly illustrate the differences between static symptom network analysis models under network theory and traditional biological reductionist thinking, we selected seven highly correlated symptoms from DSM-5 as a schematic diagram (the exclusion of all 11 symptoms primarily considers that most substance addicts do not exhibit all symptoms, and the number of symptoms selected depends on researchers' theoretical assumptions; a smaller number of symptoms in the schematic aids clear presentation). These seven symptoms are: 1) tolerance (development of drug tolerance); 2) withdrawal (withdrawal reactions after reduction or cessation); 3) craving (intense desire to use the substance); 4) high-risk use (persistent use despite obvious harmful consequences); 5) reduced activities (giving up or reducing important social or recreational activities due to substance use); 6) responsibility failure (failure to fulfill work, school, or family obligations due to repeated substance use); and 7) social problems (continued use despite substance-related social or interpersonal problems). In the latent variable model of substance addiction based on biological reductionism, all symptoms are attributed to some common physiological cause, similar to how lung cancer patients exhibit symptoms such as coughing, wheezing, and chest tightness due to cancer cells—if cancer cells are completely eliminated, symptoms will also disappear (left side of [Figure 1: see original paper]). However, in the network analysis model, symptoms form an interacting homeostatic network, no longer independent of each other, without a latent common physiological cause with priority. Any nodal symptom can potentially activate another node in the system, influencing the generation of other related symptoms and thereby affecting the entire system (right side of [Figure 1: see original paper]).

Figure 1. Schematic diagram of relationships among substance addiction symp-

toms in latent variable models based on biological reductionism and network analysis models under network theory. The left side shows the latent variable model, assuming a common physiological cause (the central black C) leading to various symptoms; the right side shows the network analysis model, where arrows represent interactions among nodes, and the close connections among symptoms form a stable whole.

Network theory focuses on connections and interactions among symptoms. Static network analysis models constructed from cross-sectional data can explore relationships among symptoms and the characteristics of individual symptoms and their relationships within the network. For example, by comparing similarities and differences in symptom networks across different addiction groups, we can understand which symptoms are more closely connected in different groups, what the core symptoms are, and how connected the entire network is. [**?**] pioneered the use of partial correlation network analysis models to analyze 11 symptoms of substance addiction from DSM-IV, including drug types such as marijuana, sedatives, methamphetamine, cocaine, opioids, and hallucinogens. Results showed significant differences in connections among symptoms across different substance users; for example, cocaine and methamphetamine, which have similar pharmacological effects, showed significant differences in symptom connections in their networks, possibly due to different social contexts of use.

Static symptom networks constructed from cross-sectional data shift research focus from latent physiological variables to relationships among different manifest symptom variables, providing richer information for understanding addiction phenomena. The advantage of static symptom networks lies in the convenience of cross-sectional data collection and analysis, but unfortunately, they cannot provide dynamic information or causal relationships among symptoms. Therefore, exploring the dynamic development process of addiction symptoms based on time-series data is crucial. When a node in the symptom network is activated, it may further activate other "adjacent" symptoms in the network. For example, when withdrawal symptoms intensify, related symptoms such as craving also increase. This phenomenon resembles synchronized behavior in a flock of geese, where the movement of one goose affects neighboring geese.

4.2 Stability and Change of Symptoms in Network Systems

Network theory not only focuses on static connections among symptoms but also introduces complex systems perspectives, viewing the mutual influence among psychological disorder symptoms as a dynamic whole. As mentioned in the goose flock example, individual geese are only influenced by nearby individuals, but the entire flock exhibits regularity and dynamic formation adjustment as a whole. Similarly, research shows that in substance addiction, coping skills (psychological factors) can influence drinking behavior (specific behavior), and drinking behavior itself also affects coping skills [**?**], which in turn may affect cognition, craving, and emotional states [**?**]. Although these studies are not network analysis models targeting symptoms themselves, they provide a foundation for including observation variables related to physiology, psychology (including symptoms), and environment as nodes in the network and examining their dynamic development and changes. The dynamic changes in network theory are manifested not only in the dynamic process of individual symptoms changing over time but also in the interactions among different symptoms and causal inferences based on network states at different time points. Therefore, from the perspective of network analysis models, this dynamism is not only temporal but also a system model formed by multiplying interactions among nodes within the system with temporal scales.

The holistic view of network theory further posits that a complex system will transition from one stable state to a new stable state (equilibrium) due to interactions among nodes. Breaking stability and changing to another state requires crossing an energy barrier, i.e., exceeding some critical threshold. This stable-state characteristic of networks has important implications for addicts' recovery and relapse. Whether in treatment or recovery, dormant symptoms can be activated by external stimuli. When the activity level of symptoms in the entire network system exceeds a certain critical threshold, the individual falls into a relapse state. For example, when facing stressful events, addicts' negative emotions lead to significantly increased drug craving [?, ?]. If individuals in early withdrawal lack corresponding coping skills and support, leading to further deterioration of life conditions, symptoms quickly spread from activation of individual symptoms to the entire network through network pathways, ultimately causing addiction relapse. Even after the initial stressful event disappears, because the symptom network has entered a new addiction homeostasis, symptoms do not disappear with the stressor. As shown in [Figure 2: see original paper], this persistence of symptoms after external stressors disappear is consistent with the lag phenomenon observed clinically, where symptoms rarely decrease after stressful events disappear [?, ?] but rather enter a stable relapse state, as shown for the addict at time t+3 in [Figure 2: see original paper]. Once individual symptom activation in the network exceeds a critical point, a stable causal feedback loop forms. This loop is self-sufficient, i.e., self-reinforcing, and external factors are no longer necessary drivers of symptom development [?]. [?] borrowed the double-well potential model from chemistry [?] to explain this phenomenon, suggesting that the transition of psychological disorders from a "healthy" state to a "diseased" state is like the state transition of chemical substances due to temporary increases in surrounding temperature—once energy exceeds a critical point and passes through the energy barrier, a new stable state is reached (see the double-well potential curves for substance addicts and recovered individuals in [Figure 2: see original paper]). For addiction, research has found that among opioid addicts who have been abstinent for more than five years, relapse rates drop from 90% to 15% [?, ?], possibly indicating that recovered individuals' symptom networks also enter a relatively stable state after long-term abstinence. At this point, individuals have more resources or skills to cope with external stimuli, and symptom networks have lower connectivity, requiring higher energy to cross the barrier and making it difficult to fall back into addiction. When stressful events subside, the partially activated symptoms of recovered individuals also decrease and gradually return to a dormant state, as shown in the recovered individual section of [Figure 2: see original paper]. The different network structures of recovered individuals and addicts provide a possible explanation for their different coping patterns and health statuses when encountering the same stressful events.

Figure 2. Schematic diagram of the development process of symptom networks for substance addicts and recovered individuals and corresponding double-well potentials. At time point t, symptoms are dormant, and both addicts and healthy individuals show healthy states (all nodes are light gray). At time point t+1, a stressful event occurs, and both groups show symptoms S2 and S3 (black nodes), with the network as a whole moving toward a critical state. At time point t+2, due to differences in network connectivity, recovered individuals have not reached the critical point, while addicts have exceeded it. At time point t+3, after the external stressful event disappears, recovered individuals return to a healthy state, while substance addicts, having crossed the critical point at t+2, enter an addicted state.

4.3 Integrated Multi-Level Network Framework

Network theory no longer assumes priority among different factors but instead treats physiological, psychological, and environmental factors at different levels as parts of the entire system, incorporating them into a unified framework. Based on network theory, some researchers have begun exploring interactions among different levels of factors in psychological disorders, including symptoms and environment, personality, and even symptoms of different psychological disorders [**?**, **?**, **?**].

As previous research has found, adversity such as early trauma, poverty, and lower social status all affect activation levels of D2 and D3 receptors in the brain [**?**]. With drug use, reduced synaptic density in the prefrontal cortex and functional disconnection with the striatum also affect individuals' planning, decision-making, and delay discounting performance [**?**], reflected in addicts' lack of life responsibilities and increased frequency of drug use in high-risk situations. According to principles of neural plasticity and "use it or lose it," the prefrontal cortex neural synapses related to advanced cognition that help addicts escape predicaments and engage in rational decision-making and planning are gradually "pruned,"and activities requiring advanced cognitive cortex participation become increasingly rare [**?**]. Addiction symptom networks become increasingly stable under physiological influences, and increasingly severe and habitual addiction symptom behaviors further accelerate physiological structural changes in the environment. Drugs have enormous physiological impacts on addicts, while psychological and environmental factors further amplify the difficulties addicts face in escaping their predicaments. Attributing addiction phenomena solely to physiological changes may overlook important relationships between other factors and addiction behaviors.

Network theory understands addiction phenomena from a larger system and provides an integrative framework. As shown in [Figure 3: see original paper], a network system composed of brain physiological level, symptom behaviors, individual proximal environment, and distal culture forms an integrated whole. Symptoms, as one level in the entire system, are influenced not only by the network structure of interactions among symptoms but also constrained by factors from other levels at different hierarchies. Research has shown that addicts with more social resources maintain abstinence longer [?], and their critical threshold for falling back into addiction is also higher. Incorporating factors that directly affect individuals, such as family atmosphere, social support, community environment, and economic income, into the network helps understand how the same stressful events have different impacts on symptom systems. Moreover, a larger network considers indirect influencing factors shared by the region where addicts live, such as beliefs, moral norms, and collective values. Compared to systems composed of symptom networks, these indirect influencing factors form relatively stable networks with more profound effects on individuals. Network nodes at different levels are connected through certain parameters, like gears of different conversion ratios, jointly depicting the overview of substance addiction phenomena.

Figure 3. Schematic diagram of an integrated multi-level factor network framework for substance addiction. The brain represents the neurobiological mechanisms of substance addiction, which are related to nodes at the symptom level (light gray). Different addiction symptoms involve different biological (the brain in the center of circles) and social (proximal environmental factors, i.e., dark gray nodes in the example) factors, which together form interacting network feedback loops. Meanwhile, the neurobiological mechanisms, addiction behaviors, and proximal environmental factors of addicted individuals are embedded within a larger sociocultural context (distal cultural factors, i.e., black nodes in the example).

Ignoring changes brought by distal factors may cause short-sightedness in treatment plan design, leading to overly high expectations that changes in certain specific factors will bring prominent effects to the entire addiction system treatment. Viewing substance addiction phenomena from a larger context also aligns with individualized difference treatment. After assessment, addicts whose core issues are physiological factors may only need to focus on changing physiological nodes to achieve good results, while excessive attention to psychological and environmental factors may hinder recovery. For example, in substance addiction treatment, using only nicotine replacement therapy or methadone maintenance treatment can effectively reduce drug use in some addicts [?, ?]. However, for other addicts with multiple relapses, the situation may be more complex. This group' s symptom networks may also be mixed with psychological and environmental factors. Clinical trials of heroin maintenance treatment conducted in Europe may represent this situation. When registered heroin addicts were allowed access to high-purity heroin, some addicts' health began to improve, crime rates decreased, and more people began seeking legitimate work; but other drug users did not stop using, and instead, their heroin dosage became increasingly larger [?].

Network theory considers the mutual influences of more factors, enabling people to view the internal mechanisms of substance addiction from a more comprehensive and systematic perspective. However, integrating data from different levels (e.g., physiological and psychological data) into the same model for analysis is by no means easy; correlations between brain physiological changes and addiction behavioral performance variables are often low. Most models simply treat physiological variables as moderating variables in statistical processing to determine the strength of connections between two symptoms, but this solution comes at the cost of increased false positives. To avoid reductionist explanations that use lower-level physiological concepts to explain higher-level phenomena and to achieve integration of multi-level factors, network theory first needs to theoretically construct connection patterns among factors at different levels, and second, adopt corresponding statistical models to reflect specific relationships in these connection patterns. Connection patterns among factors at different levels may have two forms: first, factors at different levels connect as a mereological structure. For example, physiological factors serve as compositional indicators of psychological variables, only forming psychological variables rather than causing specific psychological variables, just as orange segments form the whole orange rather than generating the orange [?]. Second, nested structures, where networks composed of physiological variables are nested within networks composed of psychological variables. Like Russian dolls, smaller dolls do not cause larger dolls to appear; physiological variables can be embedded in psychological variables through some functional relationship, and co-variation among different variables ultimately leads to transformation of the entire system.

Finding functions that connect variables at different levels and establishing a more integrated model is extremely challenging yet promising work. Since it involves psychiatric theory, mathematical foundations, and computer applications, this work requires not only clinical psychologists but also more interdisciplinary collaboration.

4.4 Treatment and Recovery of Substance Addiction Under Network Theory

As mentioned above, the ultimate goal of substance addiction network theory is clinical utility. Previously, substance addiction explanation or treatment typically targeted resolution of some physiological dysfunction as the goal. For example, dopamine system defects are often considered the essential cause of drug addiction [?], leading to many theories using single causes for biological reductionist explanations [?, ?], hoping to solve drug addiction problems by addressing dopamine system defects. However, addiction treatment models based on biological reductionism soon failed in practice [?]. While treating based on biological reductionism, only a few researchers focused on complex systems composed of factors at different levels [?]. Gradually, however, researchers began to recognize the advantages of treatment based on complex systems, which mainly involve viewing substance addiction holistically and no longer isolating physiological, environmental, and psychological factors, enabling discussion of behavior change within a larger context. Therefore, physiological factors are no longer considered decisive causes of substance addiction. When using medication to help individuals withdraw, we also pay attention to addicts' interpersonal relationships and whether reducing certain addiction symptoms can alleviate activation of other symptoms in the network, thereby restoring relatively healthy levels.

Network theory can provide new references for assessment and diagnosis. Clinical workers no longer only obtain information by determining the number of symptoms or total scale scores. Instead, they assess the status of symptoms and their interactions through networks and evaluate the dynamic change processes of symptom nodes to maximize information available for treatment. Research on critical points in substance addiction dynamic systems mentioned above shows that if intervention timing is close to the critical point, it will cause greater perturbation to the system [?] and can measure network critical points through momentary assessment techniques [?].

Based on assessment information, [?] suggests at least three directions for network-based intervention: first, direct intervention on symptoms to change the status of one or more symptoms, such as using medication to directly reduce withdrawal reactions in addicts during treatment; second, intervention on external stimuli to reduce the intensity of external stimulus sources, such as avoiding cue stimuli or reducing the intensity brought by stressful events; and third, changing connections between symptoms, such as when drug users spend large amounts of time on drug use, believe they are worthless, develop beliefs that they are not worthy of being liked by others, resultantly avoid social activities, and experience more interpersonal problems. Using cognitive therapy to intervene on beliefs can help adjust connections between symptoms and achieve better therapeutic effects.

Currently, many effective treatment methods have been used in substance addiction intervention. Both pharmacological treatments targeting physiological bases and psychologically related cognitive-behavioral therapy may help addicts recover. However, early substance addiction theories were mostly based on biological reductionist explanations, targeting interventions at a few variables and lacking holistic perspective to observe the status and change processes of complex systems, making it difficult to integrate intervention methods at different levels into a coherent framework. Network theory can effectively combine various intervention methods based on obtained system dynamic change information to develop personalized intervention plans, aiming to restore the entire network to a healthy state and help addicts return to society.

5. Limitations and Future Directions

Addiction has plagued humanity for thousands of years. Today, despite technological capabilities to observe brain neural and molecular-level changes, persistently high addiction relapse rates remain worthy of reflection while efforts continue to seek physiological markers of addiction.

[?] once asserted: "Currently, no psychological disorder can be regarded as an entity in taxonomy." Substance addiction, eating disorders, and mood disorders all have problems with blurred boundaries and insufficiently determined thresholds [?]. With historical and cultural changes, addiction phenomena, like many complex phenomena in nature, present different characteristics in different periods. Any model that simplifies substance addiction to a single physiological or environmental factor may be futile.

Based on critiques of early single-factor addiction models and clinical research findings, some researchers have proposed similar dynamic network models of substance addiction that no longer assume some factors are more influential than others but instead believe any tiny factor may affect unstable systems and cause relapse behavior [?]. However, this theory may be limited by the development process of models and has not yet developed corresponding statistical models for application in substance addiction. Network theory provides an integrative framework for complex factors in substance addiction, exploring from a dynamic systems perspective to remedy the long-standing split between psychological and biological domains in psychopathology research originating from Cartesian dualism. Current network analysis models based on relationships among addiction symptoms may be a good starting point for applying network theory to practice. It should be noted that current network theory research still lacks rigorous empirical testing and has some shortcomings [?]. First, although relationships among nodes in network theory are not only correlational but may also be causal, there are currently very few studies that rigorously verify causality among nodes. Longitudinal studies are still lacking, making the clinical significance of statistical indicators in studies using network analysis models still controversial [?] and difficult to directly provide supporting or refuting evidence for network theory hypotheses. Second, most existing cross-sectional data network studies use existing databases that were not originally collected to study psychological disorders as complex network systems. Therefore, the research design itself was not intended to verify network theory. Moreover, the scale items used for the same psychological disorder differ across studies (in 18 independent depression network theory studies, researchers used 12 different depression measurement scales) [?], making it difficult to assess whether existing data can effectively represent the essence of a psychological disorder [?, ?]. Finally, most existing network analysis model data come from observational studies that primarily obtain information by asking psychiatrists whether a symptom exists, lacking experimental studies that manipulate independent variables to obtain causal relationships among variables. Observational study designs help understand the appearance of a psychological disorder and propose reasonable network structure hypotheses but cannot directly prove causal relationships among different factors/nodes posited by network theory.

Overall, the complex systems theory that incorporates different levels of addiction data into networks still belongs to verbal models, with few studies elaborating on interactions within the system in detail. This is also a focus for future development of network theory in psychiatry, and computational models play a key role in achieving this goal [?]. Recently, some researchers have attempted to apply such computational models to depression and panic disorder studies, trying to predict depression and panic disorder systems [?, ?]. In the future, with continuous development of computational tools and network analysis models, the complex interaction processes among factors will be further clarified and presented in quantitative form. Particularly when combined with longitudinal tracking studies and experimental methods, causal relationships and interactions among symptoms can be verified. Additionally, using the advantages of network theory in dynamic systems, nodes in substance addiction networks can involve not only symptom changes but also intentional content from human higher cognition as key nodes in network models, serving as a bridge linking dynamic changes between physiological and psychological states.

This article introduces network theory, providing a perspective different from biological reductionism for viewing substance addiction phenomena. In network theory, substance addiction no longer focuses entirely on biological "entity" causes but is instead a system maintained by multi-factor interactions. This interaction model provides at least three new ideas for current addiction research: first, directly focusing on individual symptoms and their interrelationships rather than treating them uniformly as only indicators for final diagnosis or components of total scale scores; second, using dynamic systems perspectives to understand concepts of individual addiction and recovery, where symptoms in the system are no longer manifestations of some latent cause but mutually influence and reinforce each other, thereby affecting the overall system structure. As system changes accumulate quantitatively over time and exceed some threshold, individuals transition to another stable state; third, providing an integrative framework for multi-level factors that no longer views addiction physiological mechanisms as central but constructs complex systems where physiological, psychological, and environmental factors serve as different pathways that may all cause individuals to fall back into addiction states through feedback loops. Placing substance addiction phenomena within larger systems may integrate different levels of data into the same model to observe the influence of different factors on human addiction. This holistic view can avoid the limitation of "seeing only trees but not the forest" and help bridge historical divisions in substance addiction research that treated body, mind, and environment as independent factors, opening a new path for substance addiction research.

Note: Figure translations are in progress. See original paper for figures.

Source: ChinaXiv —Machine translation. Verify with original.