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A network perspective on heroin use: associations between craving, withdrawal symptoms, dependence, loss of control, and psychosocial consequences

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ABSTRACT

Background: Opioid use disorder (OUD) is a complex diagnosis characterized by symptoms such as craving, tolerance, withdrawal, and impaired social, occupational, or recreational activities. However, there is a lack of data about the interconnectedness of these symptoms, in particular the links between withdrawal symptoms and psychosocial impairment. The present study uses symptom network analysis to better understand these associations surrounding heroin use.

Methods: We used data from individuals who reported heroin use during the past 12 months in the National Survey on Drug Use and Health (NSDUH) (year 2021, n = 207). We estimated a cross-sectional network that included heroin use-related aspects, including coping and withdrawal symptoms, consequences, loss of control, craving, and dependence symptoms. To examine key 'bridge nodes' that connect these different clusters, we computed a measure of bridge expected influence for each node.

Results: The network model revealed several symptom connections within and between clusters. The withdrawal symptom, sleep problems, had the strongest bridge centrality. The dependence symptom "increased use for an effect", was a key bridge node connecting to withdrawal symptoms and consequences. Craving was connected with two withdrawal symptoms (depressed mood and sweating). Additional symptom connections emerged between the loss of control and other dependence symptom nodes.

Conclusions: Our network analysis model provides additional insight into how heroin use symptoms and relevant characteristics are interconnected. Craving and loss of control (time spent using, amount of use) map onto specific withdrawal symptoms.

1. Introduction

Opioid use disorder (OUD) continues to be a critical public health concern in the United States (US). Estimates from a 2019 review indicated that between 6–7 million people have OUD in the US (Keyes et al., 2022). Despite the decline in opioid prescriptions, as reported by the Centers for Disease Control and Prevention (CDC) (Dowell et al., 2022), trends have shown that heroin use has increased. Furthermore, OUD-related deaths have been on the rise, reaching a record high in 2021 with 106,699 overdose deaths (Spencer et al., 2022; Stringfellow et al., 2022), especially with fentanyl, a synthetic opioid, playing a major role in these fatalities due to its high potency.

OUD is a multifaceted diagnosis and includes symptoms of craving, tolerance, withdrawal, and impaired social, occupational, or recreational activities (American Psychiatric Association, 2013). It can include the use of heroin, fentanyl, or other strong prescription pain relievers (Dydyk et al., 2025). According to the DSM-5, individuals who meet more than 2 out of 11 specified criteria are considered to have a mild severity of OUD. Yet, there has been limited research on the structure of associations (i.e., co-occurrence) between different OUD symptoms and their dynamic interplay, which poses a hindrance to understanding the persistence of OUD (Cavallo et al., 2013; Hu et al., 2020; Jeon et al.,

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2024).

To understand the partial (correlational) structure and dynamics between symptoms, various symptom network analysis tools have been proposed (Borsboom & Cramer, 2013; Freichel, 2023). According to network theory, mental disorders originate as a result of the interconnected causal relationships between various symptoms (Borsboom, 2017; Borsboom & Cramer, 2013). Symptom network models consist of nodes that are connected through edges (i.e., partial pairwise associations) that control for all other variables in the model. Unlike traditional latent variable models, symptom network models allow us to examine the interplay between specific opioid use symptoms (nodes) as interacting components of a dynamic system (Borsboom & Cramer, 2013) while controlling for all other factors included in the network. This approach enables the identification of (1) 'bridge nodes' (Jones et al., 2021) that link distinct symptom clusters (e.g., withdrawal symptoms and craving), (2) the centrality of specific variables based on their overall interconnectedness (Bringmann et al., 2019), and (3) the clustering of variables into meaningful communities (e.g., dependence symptoms and physical withdrawal) (Borsboom et al., 2021). These statistical network properties may offer insights potentially relevant for clinical intervention efforts – for instance, there is an ongoing debate and mixed evidence for the utility of central nodes as treatment targets (Bringmann et al., 2019; Castro et al., 2024; Levinson et al., 2022; Rodebaugh et al., 2018).

Prior research has used network models for studying the structure of substance use disorder (SUD) symptoms, with the majority of studies focusing on alcohol- and cannabis-use disorder (Freichel et al., 2023; Huth, Luigjes, Marsman, Goudriaan, & van Holst, 2022; Rhemtulla et al., 2016; Freichel et al., 2023). To the best of our knowledge, there are only a few studies investigating heroin use-related characteristics using network analysis. For instance, Rhemtulla and colleagues (2016) estimated a cross-substance network and separate network models for each substance, one of them being opioids. They examined the eleven OUD symptoms in the individual network and found that tolerance was strongly associated with more than-planned substance use in the cross-substance network, and the most central node in the opioid network was that use "interferes with work/life". Similarly, Rutten and colleagues (2021) also estimated an overall symptom network and separate symptom networks between different substances. They found that spending substantial time obtaining, using, or recovering from substance use was the most central symptom in the overall network. In the opioid network, some of the nodes with the highest strength were interpersonal issues and prolonged use. Furthermore, Ingram and colleagues (2022) conducted a network analysis to examine the association between drug overdoses and symptoms of polysubstance use (alcohol, cannabis, stimulants, sedatives, opiates). Their results indicated that most symptoms were positively connected, and the strongest connections were between symptoms in the same substance group (Ingram et al., 2022). Moreover, the study found that withdrawal (after abstaining from stimulants, opiates, and sedatives) and tolerance (to opiates and sedatives) were two of the most central symptoms (Ingram et al., 2022). In addition to network analysis, latent class models have been used to identify OUD symptom subtypes based on heroin and prescription opioids, which included asymptomatic, tolerance/time, loss of control/pharmacological, social impairment, and pervasive (Miller et al., 2024).

Despite these advances, there still exists a paucity of research on OUD symptom networks that examine associations between OUD symptoms at a granular level. The present study uses a large population-wide survey dataset to examine granular associations between heroin-use-related characteristics and specific withdrawal symptoms. The aim was to examine what specific OUD symptoms are associated with withdrawal and coping, dependence, loss of control, consequences, and craving.

2. Methods

2.1. Data Source

We used the National Survey on Drug Use and Health (NSDUH) 2021 dataset (N = 69,850). The NSDUH is an anonymous annual population-wide survey in the United States that collects data on substance use and mental health among individuals aged 12 or older (SAMHSA, 2022). According to NSDUH, household addresses are randomly selected and an adult from a household is selected to complete the interview. Data was initially collected through face-to-face household interviews. However, given the COVID-19 pandemic, data collection transitioned to web-based interviews in 2020. As listed on the Substance Abuse and Mental Health Services (SAMHSA) description page: the inclusion criteria included residents of households, persons in noninstitutional group quarters, and civilians living on military bases. Exclusion criteria included: individuals who were not housed and did not use shelters, were active military personnel, and residents of institutional group quarters. Given that this dataset is public, this study was exempt from review by the Institutional Review Board (IRB).

Our analysis focuses on heroin use in the past 12 months; therefore, we excluded individuals who reported that they did not use heroin in the past 12 months. This resulted in a sample of 251 individuals. We further excluded 44 individuals with missing data on the relevant OUD variables. We intended to include fentanyl in our analysis; however, due to data availability constraints, we were unable to do so. Instead of being assessed individually, fentanyl was grouped with prescription opioids. Thus, making it difficult to disambiguate. The final sample resulted in a total of 207 individuals. We included all available heroin use-related items (see Table 1) that showed at least 30 endorsements. This was done to ensure sufficient variability in all measures to be able to estimate a network model.

2.2. Measures

We included different measures of withdrawal and coping, dependence symptoms, loss of control, consequences, and craving (see Table 1). These items referred to individuals' heroin use in the past 12 months, and they were assessed with binary responses: 1= "yes" and 2="no".

2.3. Data analysis

We estimated an Ising model for binary data using the eLASSO algorithm. This approach uses Least Absolute Shrinkage and Selection Operator (LASSO) regularized nodewise logistic regressions with the extended Bayesian information criterion (EBIC) to select the regularization parameter. The resulting network contains pairwise associations between nodes while controlling for all other nodes in the network. The thickness of the edges describes the strength of associations. The color signifies the respective direction of association (blue = positive, red = negative). The model was estimated using the *bootnet* R package (Epskamp & Fried, 2015) and visualized using the *qgraph* R package (Epskamp et al., 2012). After estimating the network, we then computed bridge centrality, namely bridge expected influence (1-step), and rescaled it relative to the maximum possible inter-community connectivity (Jones et al., 2021). Bridge centrality quantifies the extent to which a node A is connected to nodes that are not in the same community as node A. For instance, high bridge centrality of the node "sleep problems" would indicate that sleep problems are most closely related to non-withdrawal symptoms or nodes that are outside the "withdrawal" cluster. Finally, to quantify the stability and accuracy of the estimated network structure and centrality measures, we used a non-parametric bootstrapping procedure with 1,000 bootstraps (Epskamp et al., 2018).

Table 1
Heroin use network node name, and the respective item and cluster.

Respective Node Name	Respective Cluster	NSDUH Item
FeelBlue	Withdrawal and coping	*Feeling kind of blue or down*
Vomit	Withdrawal and coping	*Vomiting or feeling nauseous*
Cramp	Withdrawal and coping	*Having cramps or muscle aches*
RunnyNose	Withdrawal and coping	*Having teary eyes or a runny nose*
Sweat	Withdrawal and coping	*Feeling sweaty, having enlarged eye pupils, or having body hair standing up on your skin*
Diarrhea	Withdrawal and coping	*Having diarrhea*
Yawn	Withdrawal and coping	*Yawning*
Fever	Withdrawal and coping	*Having a fever*
Sleep	Withdrawal and coping	*Having trouble sleeping*
Obligations	Consequences	*During the past 12 months, did you have any serious problems like these at work, school, or home because of your use of heroin?*
Social	Consequences	*Did you continue to use heroin even though it often caused arguments or problems with family or friends?*
Risky	Consequences	*Did you continue to use heroin even though it was causing long-lasting or repeated physical health problems or making your physical health problems worse?*
LessAct	Loss of Control	*During the past 12 months, did you give up or spend a lot less time doing any of these types of important activities because of your use of heroin?*
TimeUse	Loss of Control	*During the past 12 months, did you spend a great deal of your time using heroin, feeling its effects, or getting over the effects of heroin?*
LargerAmount	Loss of Control	*During the past 12 months, were there many times when you ended up using heroin in larger amounts or for a longer time than you meant to?*
TryStop	Loss of Control	*During the past 12 months, did you try to cut down or try to stop using heroin?* Or *Some people who use heroin try to cut down or stop but find they can't. Was there more than one time in the past 12 months when you tried but were unable to cut down or stop using heroin?*
Desire	Craving	*During the past 12 months, were there times when you wanted to use heroin so badly that you couldn't think of anything else?*
NeedMore	Dependence (tolerance)	*Do you need to use a lot more heroin than you used to in order to get the feeling you want?*
UseCope	Dependence (withdrawal)	*During the past 12 months, did you use heroin or another drug to get over or avoid having heroin withdrawal symptoms?*

3. Results

3.1. Sample characteristics

The majority of respondents fell within the category of 35 to 49 years old (37.2 %), followed by those aged 30 to 34 years (20.3 %), and 26 to 29 years (14.0 %). The sample was nearly evenly split, with 49.3 % identifying as male and 50.7 % as female. Most respondents reported that they had never been married (66.2 %), followed by those who were divorced or separated (18.4 %) and those who were married (12.6 %). 68.1 % of the sample reported ever receiving treatment for alcohol or drug use, 45.5 % reported receiving treatment for alcohol or drug use in the last 12 months, and 34.3 % reported receiving treatment specifically for heroin use in the last 12 months.

3.2. Network for opioid use disorder

The OUD symptom network is shown in Fig. 1, panel A. The network is dense (54 non-zero edges, average edge weight = 0.271) and contains withdrawal symptoms, dependence symptoms, loss of control, craving, and consequences. Within the withdrawal symptom cluster, nodes such as *vomit*, *cramp*, *runny nose*, and *sweat* are closely linked, indicating that these physical withdrawal symptoms frequently co-occur. Our network revealed several associations between clusters: *sleep* was the node with the highest bridge centrality (see Fig. 1, panel B) and was associated with 1) withdrawal nodes: *fever, cramp, and diarrhea,* and 2) dependence nodes: *NeedMore and UseCope*. *Craving* was the second highest bridge node connected to 1) withdrawal symptoms: *FeelBlue* and *sweat*, and 2) loss of control nodes: *TimeUse*, *LargerAmount*, and *LessAct*. Using heroin more than intended (*LargerAmount*) was a bridge node (see Fig. 1, panel B) connecting to nodes in all clusters (*Craving*, *TimeUse, LessAct, NeedMore, vomit, and social*). Increased use for an effect (*NeedMore*) was another bridge node (see Fig. 1, panel B) connecting various withdrawal symptoms (*sleep*, *diarrhea*) with social conflicts with friends and family.

Furthermore, social conflicts with friends and family (*Social*) serves as a key bridge node connecting to other nodes with the consequences cluster. For example, the strongest association was with serious problems at work, school, or home because of heroin use (*Obligations: Work, school, or home problems*).

In the loss of control cluster, spending a great deal of time using heroin, feeling its effects, or getting over the effects (*TimeUse*) was a key bridge node connected to another loss of control node *LargerAmount,* and *Craving*. The *TimeUse* node was strongly associated with using heroin or another drug to get over or avoid heroin withdrawal symptoms (*UseCope*). *LessAct* (giving up important activities because of heroin use) was also strongly associated with *Craving*, *Obligations* (problems at work, school, or home), and *TimeUse.* The bootstrapping stability analysis revealed suboptimal stability (correlation stability (CS) coefficient for edge: 0.29; CS coefficient for bridge centrality: 0.28). However, both coefficients exceeded the minimum threshold of 0.25 suggested by Hevey (2018).

Fig. 1, panel B shows the bridge centrality for all nodes. As described above, *Craving*, using heroin more than intended (*LargerAmount*), dependence (increased use for an effect – *NeedMore*), and sleep problems (*Sleep*) represent the nodes that show the highest level of bridge centrality.

4. Discussion

The aim of our study was to estimate a network model based on heroin use symptoms and related characteristics using the NSDUH data set. The 19 symptoms were grouped into five clusters: withdrawal and coping, consequences, loss of control, craving, and dependence symptoms. Several connections were found within and between clusters.

We believe the most striking symptom within the network is craving as it was linked to two specific withdrawal symptoms (depressed mood and sweating) and behaviors related to the loss of control (i.e., spending more time using than planned, using larger amount of heroin than planned, and giving up important activities). This aligns with a symptom network model that identified craving as a central symptom in SUD symptoms, including opioids (Gauld et al., 2023). While cross-sectional network analyses cannot establish directed temporal effects, it would be important to examine if craving exacerbates the severity of withdrawal effects and the inability to control use in future longitudinal studies. Given its association with withdrawal symptoms and loss of control, withdrawal symptoms may be a modifiable target in intervention efforts. This is in line with research that highlights the importance of targeting

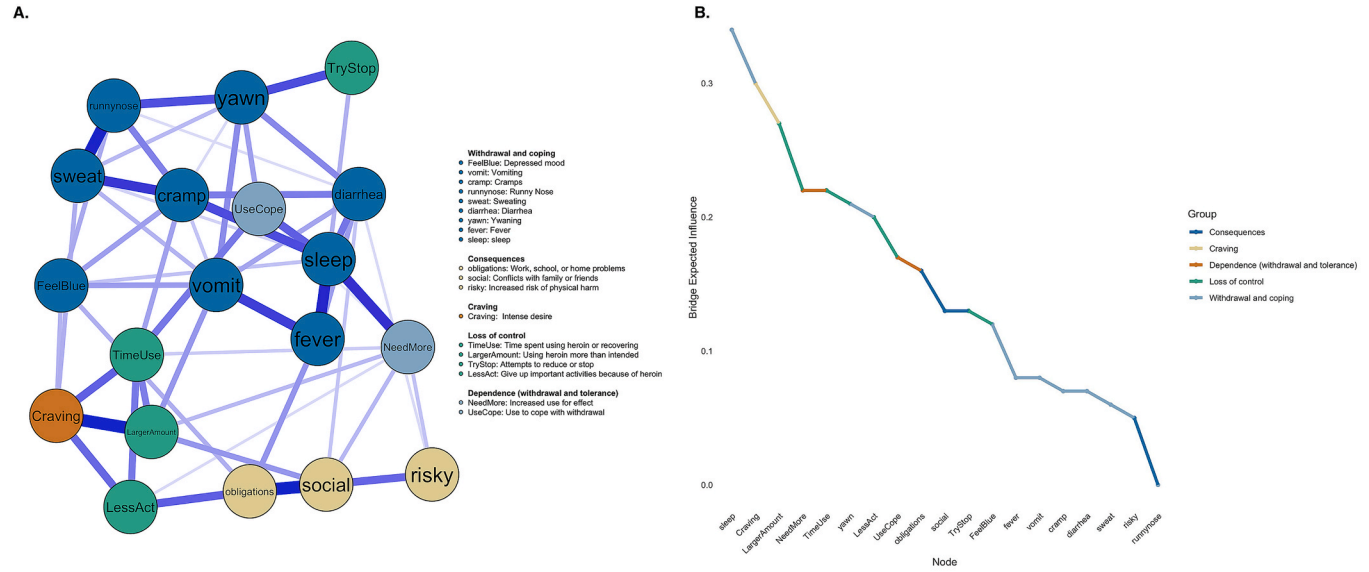

Fig. 1. *Heroin use Symptom Network Model and Bridge Centrality Estimates. Note.* Panel A shows the network model. Panel B shows the corresponding bridge centrality estimates.

craving in pharmacological and cognitive-behavioral treatments and assessing it in predicting relapse (Kakko et al., 2019).

Our network also indicated that withdrawal symptoms were interconnected, which suggests that these symptoms co-occur with each other as expected. Moreover, the key bridge node increased use for an effect (*NeedMore*) was strongly connected to the node having trouble sleeping (*Sleep*). Additionally, sleep was the strongest bridge node and was strongly connected to another withdrawal symptom, using heroin or another drug to get over or avoid having withdrawal symptoms (*UseCope*). These connections indicate that the more trouble one has sleeping while experiencing withdrawal, the more one may use heroin or another drug to alleviate this symptom and may use a lot more heroin to get the desired effect (Bluthenthal et al., 2020). This is supported by past literature indicating an association between withdrawal symptoms and sleep disturbances (Beswick et al., 2003). Time spent using heroin or recovering (*TimeUse)* was also linked to using heroin to cope with withdrawal (*UseCope) and* using more heroin than intended (*LargerAmount),* which is consistent with previous network analyses (Rutten et al., 2021).

Furthermore, symptoms in the consequences cluster, specifically negative health and psychosocial impairment, were interconnected. Giving up important activities because of heroin use (*LessAct*) was related to problems at work, school, or home (*Obligations*), *Craving*, and *TimeUse.* This indicates that giving up important activities because of more time spent using or craving heroin may lead to negative social consequences. The conflicts with friends and family *(Social)* node was also strongly associated with problems at work, school, or home *(Obligations)* node. This suggests that individuals who continue to use heroin (even though it often leads to conflicts with family or friends) experience serious issues like problems at work, school, or home. One study found that family conflict was a significant predictor of increased injection drug use in individuals who were addicted to heroin (Knight & Simpson, 1996). This suggests that family and friend conflict is a potential area to address in future interventions. Loss of control nodes were all interconnected. This is expected as the key features of heroin or opioid use dependence are spending more time and using larger amounts of heroin/opioids to feel its effects (Jalali et al., 2020).

A major strength of our analysis is the inclusion of all relevant DSM-5 criteria for OUD along with additional relevant characteristics such as physical withdrawal symptoms (e.g., vomiting, cramps, sweating, diarrhea, fever, sleep). As described above, one symptom we identified was sleep problems. This is important because our network estimated that sleep was strongly connected to dependence symptoms while controlling for all other nodes in the network. To our knowledge, this finding did not seem to be reflected in previous network analytical studies. Another strength is that we look at partial connections between these factors while controlling for all other nodes. Most previous studies looked at bivariate associations that cannot disentangle the effects of other symptoms. These results highlight the significance of physical withdrawal symptoms, and their potential to precipitate symptoms such as craving, increased use, or using a larger amount.

4.1. Limitations

There are several limitations in this study. First, the data used in this analysis was cross-sectional. To understand how OUD symptoms and related use characteristics interact over time, longitudinal data is needed. Second, the data was self-reported, making it possible that respondents underestimated their heroin use (Reuter et al., 2021). Third, this network only estimated heroin use, and not other opioids such as prescription opioids or fentanyl. Especially because the 2021 data was used and since then there has been a rise in fentanyl-contaminated heroin (Zhao et al., 2024). Individuals who have been exposed to fentanyl-contaminated heroin may experience certain symptoms differently (Carroll et al., 2017). Therefore, it is critical to include questions about fentanyl use in upcoming national surveys to estimate a more comprehensive network model. Fourth, we estimated a network model for individuals who reported heroin use within the past 12 months, revealing substantial variation across all symptom and characteristic measures. Future research should replicate these findings in larger clinical samples of individuals with OUD. Lastly, 34 % of our sample indicated they were in treatment for heroin use in the last 12 months. The treatment effects could have directly influenced the symptom presence and the associations between symptoms. For instance, 1) medication for OUD (MOUD) such as buprenorphine could have reduced craving (Baxley et al., 2023). Moreover, 2) cognitive-behavioral therapy, including behavioral activation, may have weakened links between craving and giving up important activities by increasing engagement in rewarding, goal-directed behaviors (McHugh et al., 2010).

4.2. Future directions

Future research also should examine the interplay between symptoms and use characteristics at different time scales. For instance, idiographic (i.e., person-specific) networks may be used to examine how the associations between OUD symptoms vary among individuals over the course of hours; however, there may be challenges with this (Reeves & Fisher, 2020), such as the need to obtain a large number of observations in ecological momentary assessment. In addition, future research could also estimate panel networks to examine the temporal interplay of OUD symptoms across extended time windows, such as weeks and months (Freichel et al., 2023).

5. Conclusions

This brief report provides additional insight into how specific withdrawal symptoms, negative psychosocial consequences, behaviors related to loss of control, dependence, and craving are interconnected. To the best of our knowledge, this is one of the first investigations of such interconnections using network analysis in a sample of individuals who used heroin recently. Our findings underscore the importance of craving and loss of control in exacerbating withdrawal symptoms and negative psychosocial consequences.

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Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used AI-powered language tools to improve grammar and language use. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

CRediT authorship contribution statement

Veronica Szpak: Writing – original draft, Formal analysis, Conceptualization. **Joji Suzuki:** Writing – review & editing, Conceptualization. **Reinout W. Wiers:** Writing – review & editing, Conceptualization. **René Freichel:** Writing – review & editing, Writing – original draft, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data can be accessed through the Substance Abuse and Mental Health Data Archive (SAMHDA).

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