# Curating Recovery All-Round: Network Analysis of Patients' Internal and External Factors in Substance Use Disorder Treatment

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**Abstract**

Network theory perceives mental disorders as a network of interconnected symptoms influencing each other instead of latent variables of a diagnosis. A similar approach is taken in inpatient treatment for substance use disorder (SUD) by treating the psychological factors and curating the contextual factors related to substance use. Since previous studies have found contextual, psychosocial, and mental health factors to influence SUD recovery and outcome, it is important to understand these inter-factor relations promoting successful and durable change. Therefore, this study aimed to investigate what role these factors play in a network of individuals in inpatient treatment for SUD. The difference between pre- and post-treatment was investigated and a distinction was made in networks of patients with and without personality disorder (PD) comorbidity at post-treatment. Data from 307 patients recruited from Norwegian treatment facilities was used. Contextual, psychosocial, and mental health factors were examined by estimating four regularized partial correlation networks (Pre-Treatment, Post-Treatment, PD, Control) and their respective accuracy and stability bootstraps. Whereas, to test the differences between these networks the NetworkComparisonTest was performed. Results of all networks indicate strong connections between depression and anxiety, and between emotional, physical, and sexual abuse. Furthermore, the Post-Treatment and PD networks show connections between contextual factors and substance use thereby illustrating the importance of a curated environment. Further investigation of contextual, psychosocial, and mental health factors through employment of a network intervention analysis in longitudinal research is important to purposefully target mechanisms of change in treatment for SUD recovery.

*Keywords:* inpatient treatment, substance use, network

# Curating Recovery All-Round: Network Analysis of Internal and External Factors of Patients in Substance Use Disorder Treatment

According to the World Drug Report (2020), 35.6 million people worldwide were known to suffer from a substance use disorder (SUD) in 2018. At present, during the covid-19 pandemic, substance use and abuse has increased substantially as coping mechanism (Taylor et al., 2021; Wardell et al., 2020). Specifically, the frequency of bingeing alcohol increased with 23% and cannabis use increased with 22% (Global Drug Survey, 2020). The current pandemic illustrates perfectly how contextual and psychosocial factors impact one's mental health. Relief from these influential life events is sought in the use of substances to self-medicate and to numb (traumatic) emotional pain and psychological distress (Gezinski et al., 2021; Prost et al., 2016; Gerrard et al., 2012; Wardell et al., 2020). Treatment is necessary to address these disrupting influences and substitute substance use with adaptive responses.

One way to treat SUD is through inpatient treatment. Inpatient treatment facilities for SUD offer a structured and organized but stimulating environment where people with addictive problems live together drug-free. Therapeutic communities (TCs), a form of inpatient treatment, are recovery-oriented and aim at psychological, social, and behavioral stability before reentering an unsupervised (outpatient) environment with more risk factors for relapse (Reif et al., 2014). Treatment focuses on reprocessing of psychological and emotional traumas, as well as behavioral traits that form the underlying trigger of substance use. Multiple factors interfere with the effectiveness of inpatient treatment: the moderating effects of treatment retention and aftercare participation influence (long-term) recovery outcome (Vanderplasschen et al., 2013). Other important influences to consider in the effectiveness of the therapeutic process and outcome, are mental health, as well as psychosocial and contextual factors.

## Mental Health, Psychosocial, and Contextual Factors

An important mental health factor that affects internalization of the techniques and methods in inpatient treatment is comorbidity. Among individuals with SUD a high prevalence of comorbidity with personality disorders (PDs) exists. (Verheul, 2001). Generally, comorbidity among patients with SUDs is a predictor of poor treatment response and outcome as it predicts SUD persistence and severity (Fenton et al., 2012; Parmar & Kaloiya, 2018) and could therefore interfere with treatment. This interference is due to a more severe SUD symptomatology, psychopathological burden, and poor social functioning associated with PD, which in treatment is manifested through decreased motivation, nonadherence, and poor therapeutic relations (Parmar & Kaloiya, 2018).

In addition, as demonstrated by the influence of PD symptomatology, psychosocial factors affect the therapeutic process in inpatient treatment. In fact, measures of psychological pain and mental distress are found to influence substance use and consequently clinical outcomes (Mee et al., 2019; Burdzovic Andreas et al., 2015). The strong associations between childhood maltreatment trauma and SUD recovery (Rasmussen et al., 2018; Fitzpatrick et al., 2020) indicate the importance of psychosocial factors at present and in one's early formative years. Specifically, exposure to trauma in early years is associated with the development of SUD and trauma affects SUD recovery later if it remains untreated, thereby illustrating the importance of addressing the relations between trauma and substance use in SUD treatment.

Furthermore, contextual factors – such as education, employment, friends, family, and leisure – are integrated as part of the therapeutic process in inpatient treatment to create adaptive circumstances in order to safeguard recovery and prevent relapse. In fact, family dysfunction has been found to be associated with higher risk of polysubstance use in adolescents, whereas parental involvement and parental disapproval of substance use were associated with lower risk (Su et al., 2017). Additionally, Su et al. (2017) found peer influence to present a risk as peer substance use was associated with an increased likelihood of adolescents' substance use, yet neighborhood cohesion protected against adolescent substance use as it decreased the likelihood. These findings exhibit the influential effects of one's environment and how it can offer both protective and risk factors. Yet, current literature lacks insight in the relations between these contextual, psychosocial, and mental health factors of individuals with SUD and the dynamic influence they exert on treatment.

**Network Approach**

As shown by the many factors related to SUD, the therapeutic process in TCs worldwide does not regard SUD as the problematic cause (Goethals et al., 2011). SUD is rather treated as an expression along with other psychosocial and cognitive-behavioral symptoms of psychological distress (Vanderplasschen et al., 2014). This approach corresponds with network theory, which disregards the common cause model whereby mental disorders are latent variables. Instead, in network theory mental disorders are perceived as a network of interconnected symptoms influencing each other (Borsboom & Cramer, 2013). Amplifying our understanding of individuals diagnosed with SUD as an interconnected network of contextual, psychosocial, and mental health factors might yield insights in the relations between these factors and substance use.

**Present Study**

It is important to achieve a better understanding of the internal and external factors of individuals with SUD in order to accommodate and adjust treatment to patients' needs and circumstances as to increase treatment effectiveness. That is why the present study will investigate the interconnectivity of contextual factors (e.g., education, income, living situation), psychosocial factors (e.g., childhood maltreatment, parental history of substance abuse), mental health factors (anxiety, depression, cognitive difficulties) and substance use at SUD treatment initiation and follow-up by using the network approach. This variability in time can help us individuate changes in factor relations that might take place during treatment.

Therefore, our aim is to explore the important differences and similarities of network structures between pre- and post-treatment, and to visualize which variable is most influential. We hypothesize significant differences in the network structure of pre- and post-treatment networks (i.e., treatment initiation and follow-up; hypothesis 1a). As explained before, previous studies have indicated that the development of SUD is secondary to a personality pathology (Parmar & Kaloiya, 2018) and that early maladaptive schemas play an important role in SUD comorbidity (Shorey et al., 2015). Therefore, we expect mental health and psychosocial factors to be the most influential in the network at pre-treatment (hypothesis 1b). In addition, the recovery-oriented TC method suggests structured activities and an organized lifestyle with social aspects to be means for recovery (De Leon & Unterrainer, 2020; Vanderplasschen et al., 2013). Coming out of inpatient treatment patients are most focused on curating these factors as part of their reintegration. That is why, in the Post-Treatment network structure we expect contextual and social factors to be most influential (hypothesis 1c).

Lastly, our aim is to compare network structures at follow-up of participants who do and do not meet the antisocial and borderline personality cut-off. Examining these different network structures after treatment might reveal the differential effects a double diagnosis can have on recovery outcome and the possible implications we can derive for relapse prevention. Based on the finding that comorbidity of SUD with other mental disorders is a predictor for poor prognosis (Parmar & Kaloiya, 2018; Fenton et al., 2012), we expect to find significant differences in the network structures of SUD patients with PD comorbidity and patients without PD comorbidity (hypothesis 2a). Our expectation is that the antisocial and borderline personality structure shows stronger connections between mental health factors, parental mental health, and drug use (hypothesis 2b).

# Methods

## Procedure

This study was conducted with a one-sample longitudinal study design using the open data set from PLOS ONE. The utilized data was collected for a 10-year prospective study on temporal changes in opiate and stimulant use in a SUD treatment cohort (Lauritzen & Nordfjærn, 2018). Patient recruitment was carried out at twenty treatment facilities in Norway, including inpatient treatment, specialized therapeutic outpatient and Opioid Maintenance Treatment. The data was gathered through face-to-face intake interviews and (self-report) questionnaires within the first two weeks of admission (baseline; T0) and at follow-ups of one (T1), two (T2), seven (T3) and ten (T4) years later.

The study protocol of the dataset we utilized was approved by the Norwegian Social Science Data Service (NSD) (97/3536) and the Norwegian Data Inspectorate (97/3536) (Lauritzen & Nordfjærn, 2018).

## Participants

In the period of January 1998 to August 2000, 481 patients initiating treatment for illicit drug use were recruited as participants. All participants gave written informed consent. Of the 481 patients in the sample at baseline, 307 (64%) received inpatient treatment, 100 (21%) received therapeutic outpatient treatment and 74 (15%) received OMT (see Figure 1). Recruited patients did not differ substantially from other patients in gender, age and drug use at baseline. The sample size of 481 at baseline decreased to 428 at T1, 410 at T2, 348 at T3, and 296 at T4. At baseline 68% of patients were male and the average age was 30.70 years (*SD* = 8.04).

The data selection for the analyses carried out in this study included only participants in inpatient treatment facilities. Therefore, the current study had a sample size of 307 patients at baseline; 277 at T1; 259 at T2; 219 at T3; and 182 at T4. At baseline 185 patients (60,3%) met the personality disorder cut-off of 84 (indicating clinical significance), 207 patients (67,4%) were male, and age ranged from 14 to 49 years.

## Measures

The variables, measured through interviews and questionnaires, can be categorized in drug use, contextual, psychosocial, and mental health factors. An overview of all the variables and questionnaires can be found in Appendix 1.

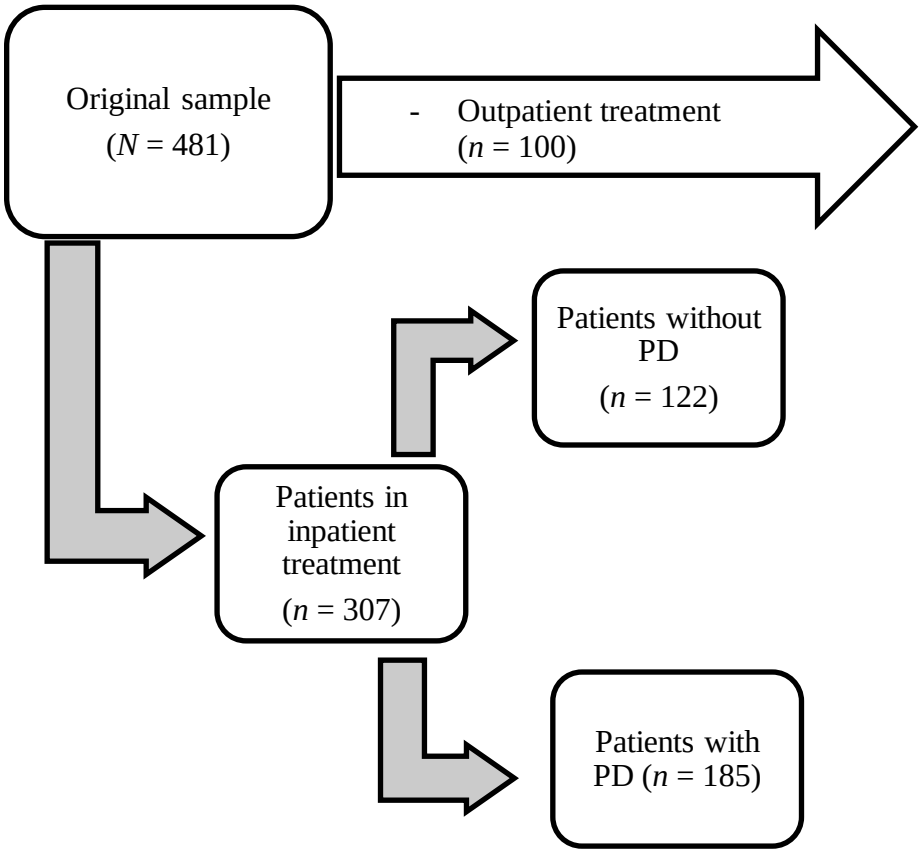
### *Substance Use*

Substance use factors address the type and quantity of substance use and whether poly-use was present. These variables were measured with the Norwegian translation of the

European adaptation of the Addiction Severity Index (EuropASI; Kokkevi & Hartgers, 1995). The inter-rater and test–retest reliabilities of the ASI vary from excellent to unsatisfactory (Mäkelä, 2004). Furthermore, the variables were also dichotomized to a no use / use response category for all follow-up assessments. Moreover, for the current study we recoded the different drug use (e.g., heroin, cocaine, inhalants) variables into two variables: overall illicit drug use and alcohol abuse.

**Figure 1**

*Flow Chart of Sample Size at Baseline*




***Contextual and Psychosocial Factors***

Contextual factors consist of education, work income, close friends, and living situation regarding substance abusive roommates. All these variables were taken from the EuropASI measure.

Psychosocial factors consist of childhood maltreatment (emotional, physical, and sexual abuse), learning and behavioral problems in primary school, parental history of substance abuse and mental health problems. The Childhood Trauma Questionnaire (CTQ; Bernstein et al., 1998) was employed at baseline to assess maltreatment and traumatic

experiences. Each type of trauma was coded at four levels: none, low, moderate, and severe. The CTQ has high internal consistency, good test-retest reliability, and satisfactory accuracy (Bernstein et al., 1994; Dovran et al., 2013). In addition, parental history of substance abuse and mental health problems was assessed with EuropASI questions.

***Mental Health Factors***

Mental health factors consist of clinical symptoms of anxiety, depression and thought disorders, and of antisocial and borderline personality traits. The self-report Millon Clinical Multiaxial Inventory II (MCMI II; Millon, 1992) was used to assess axis I psychiatric symptoms and axis II personality traits. A cut-off score of 84 and higher on the MCMI II was retained clinically significant. The MCMI II has sufficient test-retest reliability (Craig, 1999).

**Statistical Analyses**

In this study, we performed four network analyses to test our hypotheses. Networks consist of nodes (variables) and edges (connections among variables). Networks one (Pre-Treatment) and two (Post-Treatment) investigate baseline and follow-up measures respectively and include all patients in inpatient treatment. Networks three (PD) and four (Control) investigate follow-up measures of patients with PD comorbidity and patients without PD respectively. All networks consist of 16 nodes, resulting in 120 parameters. The nodes represent the variables listed in Appendix 1. Following the general rule to have at least equal numbers of observations as parameters, our sample sizes of 307, 185, and 120 can be considered reasonable (Epskamp, Kruis & Marsman, 2017).

We estimated four regularized Gaussian graphical model (GGM) networks and employed the graphical LASSO technique in combination with EBIC model selection, with a threshold set to 0.5 (Epskamp, Borsboom & Fried, 2018; Foygel & Drton, 2010). The LASSO regularization technique was used to account for possible unstable estimates by limiting the total sum of absolute parameter values and consequently dropping edge weights close to zero resulting in a sparser network (Epskamp, Borsboom & Fried, 2018). The networks' edges represent partial correlation coefficients, (due to the binary, ordinal, and continuous nature of items) which required an estimation of the variance-covariance matrix.

Furthermore, we investigated four centrality measures (betweenness, closeness, strength and expected influence [EI]) which identify the central variables in a network and potentially indicate the importance of the node due to its connectedness (Robinaugh et al., 2020). Betweenness indicates the shortest path length connecting two nodes, closeness indicates the number of connections with other nodes, and strength indicates the sum of a

node's edge weights. EI, like strength, indicates the sum of all edge-weights connected to a node, yet EI discerns between positive and negative values of edge-weights whereas strength is a summation of absolute values (Robinaugh et al., 2016). Therefore, EI is a measure that helped us assess highly influential nodes capable of activating the overall network by distinguishing between positive and negative edges.

To assess the reliability and accuracy of each network, we estimated edge-weight accuracy by computing the nonparametric bootstrap. Whereas to estimate stability of the networks, the case-dropping subset bootstrap was used and quantified with the correlation stability coefficient (CS; Epskamp, Borsboom & Fried, 2018). A *CS*(cor = 0.7) is by default set as indicator of a large effect. All network estimations including centrality indices and accuracy and stability bootstraps were carried out in JASP (JASP Team, 2020).

Finally, we used the R package NetworkComparisonTest (NCT) to compare network one (Pre-Treatment) and two (Post-Treatment); and to compare network three (PD) and four (Control; R Core Team, 2020; van Borkulo et al., 2015). The NCT consists of permutation tests for network structure invariance, which investigates statistical differences of the networks, and global strength invariance, which investigates differences between networks in the sum of all absolute edge-weights (van Borkulo et al., 2015). These tests yielded a *p*-value indicating whether a significant difference existed considering an alpha of 0.05.

***Exploratory Analysis***

We performed a network analysis to explore the contextual, psychosocial, mental health, and drug use factors of patients with PD comorbidity in inpatient treatment for SUD at 1-year follow-up. The reason behind this exploratory analysis was to see whether measures at an earlier time point than the seven-year follow-up would yield denser or more connected networks. This network comprehends the 16 nodes mentioned above which results in 120 parameters. A regularized GGM networks was estimated employing the graphical LASSO technique together with a threshold of 0.5 for the EBIC model selection. Also, JASP ran the networks using the Pearson correlation as estimation method (JASP Team, 2020). Furthermore, we investigated the centrality measures (betweenness, closeness, strength, EI) as to convey an idea of the influential nodes in the network. Lastly, we computed a nonparametric bootstrap to estimate edge-weight accuracy and the case-dropping subset bootstrap to estimate centrality stability.

# Results

## Descriptive Statistics

Out of the 307 inpatient treatment patients, 283 (92.2%) used illicit substances at baseline of which 238 (77.5%) were polysubstance use. Also, at the seven-year follow-up measure with 29.0% of missing values, 121 (39.4%) patients engaged in illicit substance use of which 86 (28.0%) were polysubstance use. Further, 185 (60.3%) patients met the personality disorder cut-off; and at baseline 166 (54.1%), 171 (55.7%), 169 (55.0%) met the anxiety, depression, and cognitive difficulties criteria respectively. The majority (59.3%) of the sample had received up to 10 years of education except for 1 participant (0.3%) who had received 0 years, whereas 20 (6.5%) patients had a stable income. These and other frequencies of the variables of interest are reported in Table 1, note the missing values.

**Table 1**

*Descriptive Statistics of Variables*

| **Variables** | | **Percentages** | | | |
|---|---|---|---|---|---|
| | | Pre-treatment | Missing at pre-treatment | Post-treatment | Missing at post-treatment |
| | Drug use | 92.2 (yes[a]); 77.5 (poly[b]) | 0.0 | 39.4 (yes); 28.0 (poly) | 29.0 |
| | Alcohol | 18.9 (yes) | 0.0 | 19.9 | 28.7 |
| Contextual | Education | 0.3 (0[c]); 59.3 (4-10[c]); 40.4 (11-15[c]) | 0.0 | | |
| | Income | 6.5 (yes) | 26.7 | 20.2 | 72.6 |
| | Living situation | 25.7 (yes) | 3.6 | 11.4 | 28.7 |
| | School problems | 63.2 (yes) | 0.7 | | |
| | Child welfare | 28.3 (yes) | 1.0 | | |
| | Close friends | 22.1 (0[d]); 68.8 (1-5[d]); 9,2 (6-15[d]) | 0.0 | 0.0 (0); 52.8 (1-5); 5.8 (6-9) | 41.4 |
| Psychosocial | Emotional abuse | 21.8 (mod-extr[e]) | 0.7 | | |
| | Physical abuse | 17.9 (mod-extr) | 0.0 | | |
| | Sexual abuse | 26.3 (mod-extr) | 1.0 | | |

| | | | | | |
|---|---|---|---|---|---|
| | Parental history substance use | 47.5 (yes) | 0.7 | | |
| | Parental history psych. Problems | 31.9 (yes) | 0.7 | | |
| Mental Health | Anxiety | 54.1 (yes) | 0.3 | 32.9 | 29.0 |
| | Depression | 55.7 (yes) | 0.3 | 30.3 | 29.0 |
| | Cognitive difficulties | 55.0 (yes) | 0.3 | 39.1 | 29.0 |

*Note.* Values represent the percentage of patients' responses to the variables at Pre- and Post-Treatment, with the response category indicated between brackets. Also, the percentages of missing values per variable at both time points are given.

[a] The response category 'yes' indicates presence of the variable. [b] 'poly' refers to polysubstance use. [c] Education is divided per years '0', '4-10', and '11-15'. [d] The number of close friends is divided per '0', '1-5', and '6-15'. [e] The 'mod-extr' response category of abuse variables indicates a moderate to extreme quantification of symptoms.

## Pre-Post Treatment Networks

### *Pre-Treatment Network*

A regularized partial correlation network of patients in inpatient SUD treatment at baseline (Figure 2A) was used to test the hypothesis (1b) that mental health and psychosocial factors are most influential in the network at pre-treatment.

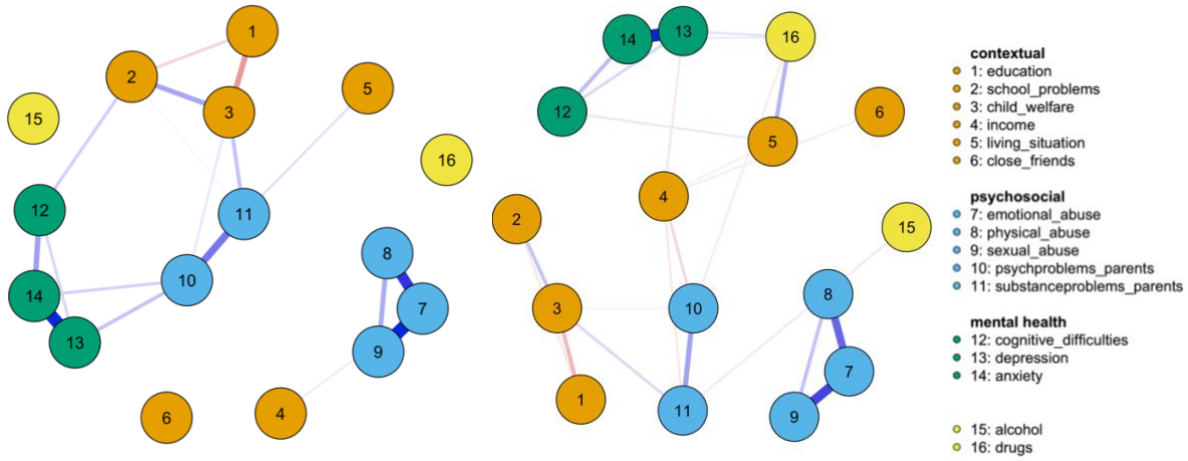
To check the accuracy and stability of the Pre-Treatment network, edge-weight accuracy and centrality stability were estimated. The edge-weight accuracy bootstrap plots the edge-weights of the sample and of the averaged bootstraps and reveals the bootstrap confidence intervals (CIs). The pre-treatment sample (Figure C1) exhibits small CIs for the negative edge-weights, illustrating that they do not significantly differ from one-another. Yet, the positive edge-weights has moderate CIs, which indicate variation in the different bootstraps and consequently only moderate accuracy. This notion calls for caution in interpreting these edge-weights. Furthermore, the centrality stability bootstrap (Figure C2) shows that if 50% of the sample were to be dropped the average correlation of the remaining sample with the original sample would still be 0.8 for strength, yet only 0.3 for betweenness. This indicates high stability (CS) for the strength centrality measure and low for betweenness. The closeness centrality measure is not shown because the number of connections between nodes resulted to be zero due to the high sparsity of the network (which also holds for the other analyses). Also, JASP does not show EI when estimating the centrality stability bootstrap. Moreover, interpretation of accuracy and stability was solely made visually since exact CI values and calculation of CS

are features not yet implemented in JASP.

**Figure 2**

*Pre- and Post-Treatment Networks*

A B




*Note.* Regularized partial correlation networks of patients in inpatient SUD treatment at A) baseline and at B) seven-year follow-up. Nodes represent contextual, psychosocial, mental health, and drug use factors. The blue and red lines represent positive and negative edges respectively, whereas the thickness of the edge indicates the strength of the correlation between nodes. Visual inspection indicates that in both networks depression and anxiety are strongly related as well as emotional and sexual abuse with physical abuse. Also, at post-treatment there are more edges between factors yet the edges at pre-treatment are thicker.

The Pre-Treatment network (Figure 2A) consists of both positive and negative partial correlations. Relatively strong positive connections exist among the anxiety and depression nodes ($r$ = .37; mental health) and among the abuse nodes ($r$ = .31; $r$ = .39; psychosocial), which cluster together. This indicates that mental health factors activate comorbidly, specifically that the presence of anxiety activates the presence of depression and vice versa. As for the abuse nodes, if the severity of emotional abuse increases so does the severity of sexual and physical abuse and vice versa. Noteworthy, the most strongly connected and therefore central node within the abuse cluster is emotional abuse. Parental history of substance use problems and previous contact with child welfare services have high betweenness centrality compared to other nodes, yet their EI is only moderate (see Figure 3A). This suggests that even though parental history of substance use problems and previous contact with child welfare services are highly interconnected, they are only moderately influential on overall activation of the network. Anxiety and emotional abuse result high on EI, differing from items lower on

centrality measures such as education, the number of close friends and living situation (contextual factors).

***Post-Treatment Network***

A regularized partial correlation network of patients in inpatient SUD treatment at seven-year follow-up (Figure 2B) was used to test the hypothesis (1c) that contextual and social factors are most influential in the Post-Treatment network.

To check the accuracy and stability of the Post-Treatment network, edge-weight accuracy and centrality stability were estimated. The edge-weight accuracy bootstrap of the Post-Treatment network (Figure C3) yield moderate to large CIs for edge-weights in the tails of the bootstrap plot, indicating that stability of the edge-weights decreases as the strength of the edges increases. The centrality stability bootstrap (Figure C4) shows that if 50% of the sample were to be dropped the average correlation of the remaining sample with the original sample would still be 0.8 for strength, yet only 0.2 for betweenness. This indicates high stability (CS) of strength and low of betweenness centrality. The accuracy and stability bootstraps of the Post-Treatment network are based on a smaller dataset than the Pre-Treatment network, consequently the sample contains less variability and is more easily subject to changes.

The Post-Treatment network (Figure 2B) also reveals a cluster of relatively strong positive edge-weights among the physical, sexual, and emotional abuse nodes ($r$ = .30; $r$ = .37). Anxiety and depression remain strongly and positively correlated ($r$ = .50). Notably, parental history of mental health and substance use problems and a stable income are highest on the betweenness centrality measures but only moderate to low on EI compared to the other nodes (Figure 3B). This is because most of their relations are weak and many relations income has to other nodes are negative. Thus, even though income is a central node, it is not influential in the network's overall activation because of its inhibiting effect. Whereas, mental health and psychosocial factors are highest on EI compared to the other nodes, specifically anxiety followed by emotional abuse and depression. Of the contextual factors, education and close friends are low on all centrality measures yet living situation is moderate compared to other nodes. Interestingly, living situation is directly related to drug use ($r$ = .15) indicating that sharing a living environment with substance- / alcohol-abusive roommates increases the likelihood of drug use and vice versa after an inpatient treatment program.

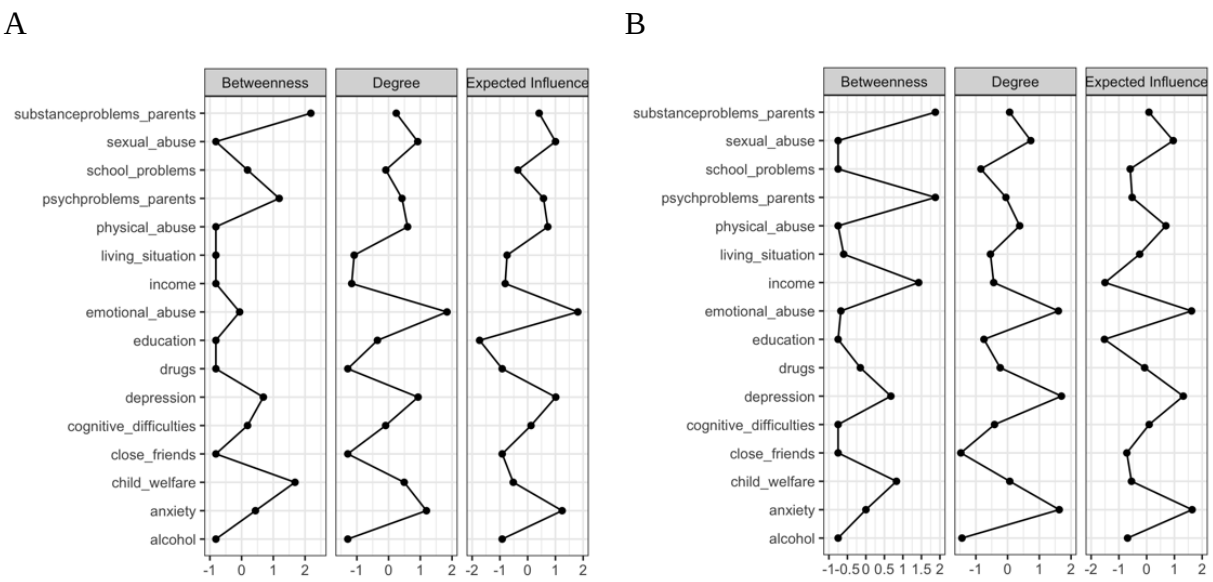
***Network Comparison***

A NCT was used to compare the Pre- and Post-Treatment networks and to test the hypothesis (1a) that they differ significantly. The NCT yielded no significant differences with respect to the network structure (test of invariant network structure; $M$ = 0.15, $p$ = .67) or the

overall strength of connectivity (test of invariant global strength; Pre-Treatment = 4.82, Post-Treatment = 2.38, $S = 0.33$, $p = .65$). These findings suggest that the alternative hypothesis that the network models derived from baseline measures and follow-up measures are different cannot be rejected.

**Figure 3**

*Pre- and Post-Treatment Networks Centrality Measures*




*Note.* Betweenness, strength, and EI measures of centrality of the nodes in the networks at A) baseline and at B) seven-year follow-up. In both networks parental history of substance use exhibits the most betweenness, or the most interconnectedness between nodes. Also, emotional abuse, depression, and anxiety result highest on the strength and EI measures compared to other nodes.

## Personality Pathology Networks

### *PD Network*

A regularized partial correlation network of patients meeting the criteria for a PD at the seven-year follow-up (Figure 4A) was used to test the hypothesis (2b) that strong connections exist between mental health factors, parental mental health, and drug use.

Edge-weight accuracy and centrality stability were estimated to check the accuracy and stability of the PD network. The edge-weight accuracy bootstrap (Figure C5) shows small CIs for edge-weights around zero and moderate CIs for stronger edge-weights (farther from zero), which indicates that the edge-weights should be interpreted carefully. The centrality stability bootstrap (Figure C6) shows high strength stability but low betweenness stability. The plot

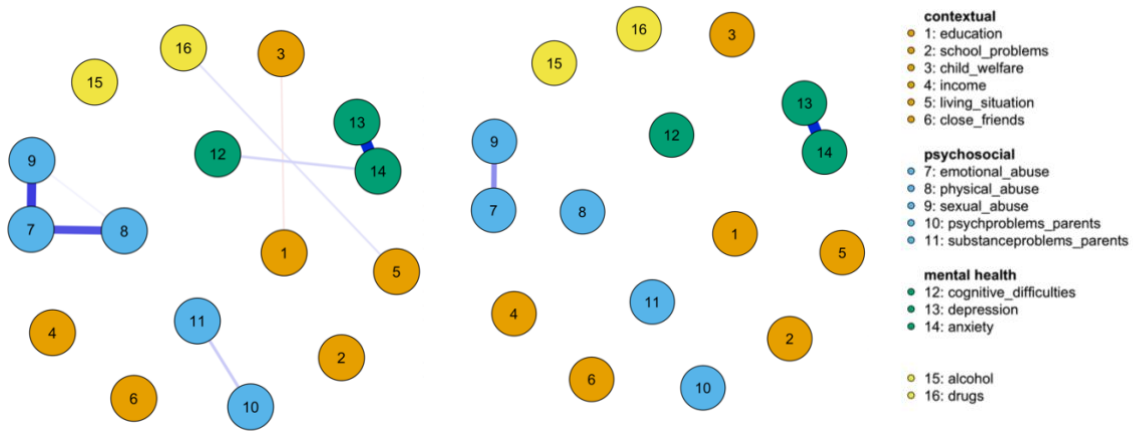
portrays that if 50% of the sample were to be dropped the average correlation of the remaining sample with the original sample would still be approximately 0.9 for strength, but only 0.6 for betweenness centrality.

The PD Network includes few non-zero edges, the percentage of edges that are zero (i.e., sparsity) is .933. The network depicts two conceptual cluster of nodes, which are not connected. This results in the centrality measure closeness to be zero. The first cluster consists of psychosocial factors, among which emotional, sexual, and physical abuse ($r$ = .30; $r$ = .27). The second cluster encompasses mental health factors - among which anxiety and depression are positively correlated ($r$ = .40). Since the clusters are not connected, the high EI of mental health factors is not indicative of centrality (see Figure 5A).

**Figure 4**

*PD and Control Networks*

A B




*Note.* Regularized partial correlation networks of patients a) with PD and b) without PD in inpatient SUD treatment at seven-year follow-up. Nodes represent contextual, psychosocial, mental health, and drug use factors. The blue and red lines represent positive and negative edges respectively, whereas the thickness of the edge indicates the strength of the correlation between nodes. Visual inspection of the networks shows their low connectedness due to absence of non-zero edges. Both networks exhibit a strong relation between depression and anxiety. Yet, the PD also exhibits strong connections between the abuse nodes and weaker connections across the network.

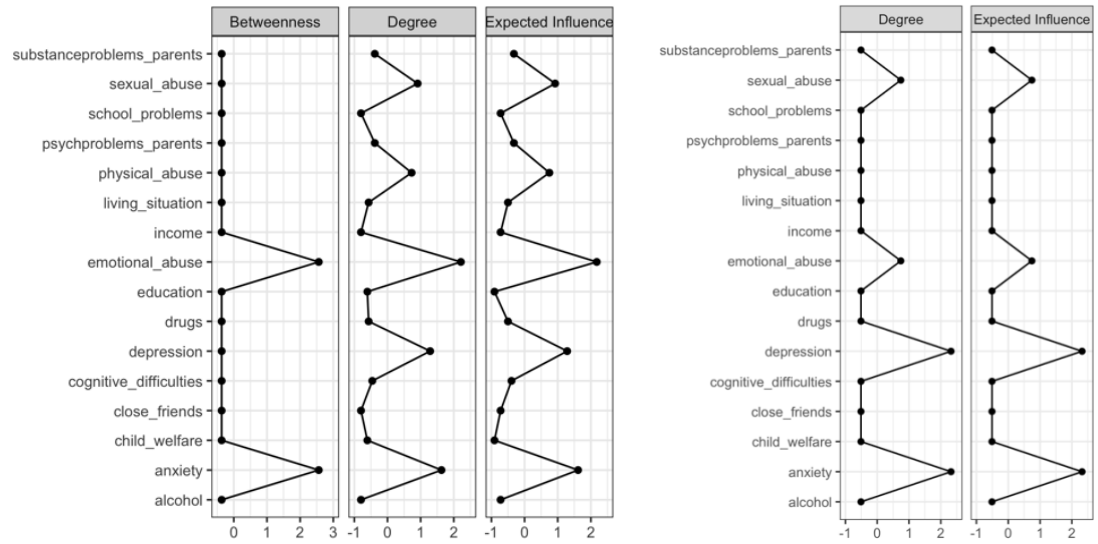
***Control Network***

A regularized partial correlation network of patients without PD at the seven-year follow-up (Figure 4B) was used as control to test against the PD network.

To test the accuracy and stability of the Control network, edge-weight accuracy and centrality stability were estimated. The edge-weight accuracy bootstrap (Figure C7) shows moderate to large CIs for edge-weights in the tails of the bootstrap plot (farther from zero), which indicates that the stronger edges are less stable than the weaker edges and should be interpreted with care. The centrality stability bootstrap plot (Figure C8) portrays that if 50% of the sample were to be dropped the average correlation of the remaining sample with the original sample would still be 0.8 for strength. Hence, strength stability of the Control network is high.

**Figure 5**

*PD and Control Centrality Measures*




*Note.* Betweenness, strength, and EI measures of centrality of the nodes in the network at A) baseline and strength and EI measures of the nodes in the network at B) seven-year follow-up. In the PD network emotional abuse and anxiety score highest on all centrality measures compared to other nodes. On the other hand, in the Control Network depression and anxiety are the highest scoring nodes. Important when reading these centrality measures is the low number of edges in both the PD and Control networks.

The Control Network includes only two non-zero edges (sparsity = .983). In fact, the network depicts two sets of nodes, and the remaining unconnected nodes. This lack of relation between nodes results in the betweenness and closeness centrality measures to be zero. The relatively stronger relation comprehends the mental health factors anxiety and depression (*r* =

.23) connected through a moderate correlation at best. Further, a weak correlation between emotional and sexual abuse ($r$ = .10; psychosocial factors) establishes the second relation in the network. Again, due to high sparsity centrality measures are not interpretable (Figure 5B).

### *Network Comparison*

A NCT was used to compare the PD and Control networks and to test the hypothesis (2a) that the networks differ significantly. The NCT yielded no significant differences with respect to the network structure (test of invariant network structure; $M$ = 0.27, $p$ = .21) or the overall strength of connectivity (test of invariant global strength; PD = 0.33, Control = 1.21, $S$ = 0.89, $p$ = .39). These findings suggest that the alternative hypothesis that the network models derived from measures of patients with PD and without PD at seven-year follow-up are different cannot be rejected.

## Exploratory Analysis

### *Descriptive Statistics*

Out of the 185 patients in inpatient treatment who met the personality disorder cut-off, at one-year follow-up 72 (38.8%) engaged in substance use of which 59 (31.8%) were polysubstance use and 15 (8.1%) values were missing. Most of the sample (68.1%) had received up to 10 years of education and 17 (9.2%) patients had a stable income. Furthermore, 61 (33.0%), 62 (33,5%), and 62 (33.5%) patients met the anxiety, depression, and cognitive difficulties criteria respectively. These and other frequencies of the variables of interest are reported in Table 3, note the missing values.

**Table 1**

*Frequencies of variables*

| | | **Percentages** | |
|---|---|---|---|
| **Variables** | | At one-year follow-up | Missing |
| | Drug use | 38.8 (yes);<br>31.8 (poly) | 8.1 |
| | Alcohol | 14.1 (yes) | 8.1 |
| Contextual | Education | 68.1 (4-10 years);<br>31.9 (11-15 years) | 0.0 |
| | Income | 9.2 (yes) | 33.0 |
| | Living situation | 17.3 (yes) | 10.3 |
| | School problems | 73.5 (yes) | 0.0 |
| | Child welfare | 37.3 (yes) | 0.0 |
| | Close friends | 17.8 (0); 67.5 (1-5);<br>6.0 (6-9) | 8.6 |
| Psychosocial | Emotional abuse | 22.2 (mod-extr) | 1.1 |

| | | | |
|---|---|---|---|
| | Physical abuse | 19.4 (mod-extr) | 0.0 |
| | Sexual abuse | 27.1 (mod-extr) | 1.6 |
| | Parental history substance use | 47.5 (yes) | 0.0 |
| | Parental history psych. problems | 49.2 (yes) | 0.0 |
| Mental Health | Anxiety | 33.0 (yes) | 8.1 |
| | Depression | 33.5 (yes) | 8.6 |
| | Cognitive difficulties | 33.5 (yes) | 8.6 |

***Network Estimation***

A regularized partial correlation network (Figure 6A) was used to explore the contextual, psychosocial, mental health, and drug use factors of patients with PD-SUD comorbidity in inpatient treatment at one-year follow-up from treatment initiation.

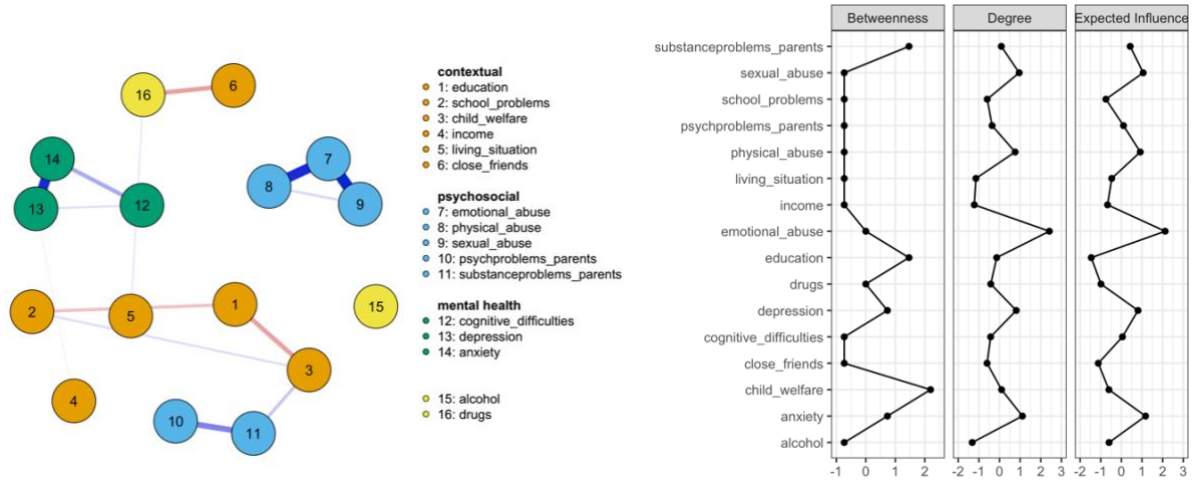
To check the accuracy and stability of the exploratory network, edge-weight accuracy and centrality stability were estimated. The edge-weight accuracy bootstrap (Figure C9) presents small to moderate CIs for edge-weights in the tails of the bootstrap plot, which indicates that the non-zero edges are sufficiently stable to be interpreted accurately. The centrality stability bootstrap plot (Figure C10) shows that if 50% of the sample were to be dropped the average correlation of the remaining sample with the original sample would be 0.88 for strength and 0.12 for betweenness. Thus, the network exhibits high strength stability but low betweenness stability calling for caution when interpreting the betweenness measure of centrality.

The network presents few non-zero edges with a sparsity of .833, which represent positive and negative relations. Apparent are the strong relations ($r$ = .38; $r$ = .34) which cluster the abuse nodes together with emotional abuse as central node. Also, another cluster is formed by the mental health factors, whereby anxiety and depression correlate strongly ($r$ = .35). Interestingly, illicit substance use is negatively related to the number of close friends ($r$ = - .14) and positively to the number of substance abusive roommates ($r$ = .04). This indicates that a smaller number of close friends and a higher number of abusive roommates increases the likelihood of activation of the substance use node. Alcohol abuse on the other hand yields null non-zero edges and therefore remains unconnected. Furthermore, parental history of mental health and substance use problems are related to other nodes characteristic of one's formative years, such as child welfare services, school problems, and education. The abuse nodes as well as anxiety and depression are highest on the strength and EI centrality measures, indicating that they are most influential in overall activation of the network (see Figure 6B).

**Figure 6**

*PD Network at one-year Follow-up*

A B




*Note.* A) Regularized partial correlation network of patients with PD in inpatient treatment at one-year follow-up. Nodes represent contextual, psychosocial, mental health, and drug use factors. The blue and red lines represent positive and negative edges respectively, whereas the thickness of the edge indicates the strength of the correlation between nodes. Visual inspection of the network indicates strong positive connections between depression and anxiety as well as the abuse nodes. The network exhibits negative edges, including the negative connection between education level and elementary school problems and between education level and experience with child welfare services. Also, the number of close friends is connected to illicit substance use through a moderate negative edge. B) Betweenness, strength, and EI measures of centrality of nodes in the exploratory network at one-year follow-up. Child welfare services scores highest on the betweenness measure compared to other nodes as it is the node with the most indirect connections. Yet, emotional abuse results highest on the strength and EI measures of centrality due to its strong connections to the other abuse nodes.

## Discussion

### Discussion of key findings

Inpatient treatment for SUD addresses the symptoms triggering substance use, ergo contextual, psychosocial, and mental health factors. Neglecting one of these factors might have repercussions on outcome and recovery. In order to amplify our understanding of individuals diagnosed with SUD as to adjust treatment to patients' needs and circumstances, we

investigated the interconnectivity of contextual, psychosocial, and mental health factors with the use of a network approach.

First, important differences and similarities of network structures between pre- and post-inpatient treatment for SUD were explored. Results show that mental health and psychosocial factors have the most influential relations in the Pre-Treatment network, yet they are not directly related to drug or alcohol use. So not the experience of anxious and depressive episodes or a traumatic experience of abuse alone is linked to a substance use response, which suggests that no single factor is an underlying cause of SUD. On the contrary, this finding stresses the influence of interconnected symptoms instead of latent variables and is thereby in line with network theory (Borsboom & Cramer, 2013). Alternatively, an explanation of the lack of relations between substance use, alcohol abuse and other factors might be the circumstances these measurements were recorded, namely at initiation of a treatment program whereby treatment intention of patients is important to considerate.

The influence of mental health factors and experiences of abuse remains high in the Post-Treatment network, highlighting a similarity between Pre- and Post-Treatment networks. In fact, our hypothesis that pre- and post-treatment differ significantly was rejected. Yet, a difference exists in that drug use and alcohol abuse show relations to contextual, mental health, and psychosocial factors at post-treatment and this does not hold true at pre-treatment. Specifically, sharing a living environment with substance abusive roommates increases the likelihood of substance use at post-treatment, thereby suggesting activation of a relapse mechanism. In fact, social ecological models illustrate how one's development and behavior are influenced by the social context and building on that, how dysfunctional contexts, upbringing, and peers influence polysubstance use (Su et al., 2018). Moreover, negative relations - mainly between income and parental influence, living situation, and depression - exist in the Post- compared to Pre-Treatment network indicating a greater inhibiting effect in the network at post-treatment. Thus, having a stable occupation and income might moderate substance use, as it affects the relation substance use has with the other factors. These findings illustrate the importance of curating one's surroundings and the benefits one can derive from it as part of rehabilitation and relapse prevention.

Second, to zoom in on the effects of SUD-PD comorbidity on recovery outcome, we examined network structures at follow-up of participants who do and do not meet the antisocial and borderline personality criteria. Our hypothesis that there are significant differences in the interrelation of factors between PD and Control was rejected. Furthermore, no relation between mental health factors, parental mental health, and drug use was found. As in previous networks,

the strongest relations exist between depression and anxiety, and between the abuse variables. Noteworthy is the rather low connectedness in both the PD and Control network. These findings are contradictory with the findings of the Post-Treatment network whereby the contextual factors appear influential in relation to substance use. Moreover, it contradicts the notion that PD-SUD comorbidity predicts poor treatment outcome, as drug use and alcohol abuse remain unrelated to other factors for PD patients (Fenton et al., 2012; Parmar & Kaloiya, 2018). Yet, as will be discussed in the limitations of this study, no interpretation is warranted because of the high number of missing values in both the PD and Control network.

Finally, the interconnectivity of contextual, psychosocial, and mental health factors of patients with PD-SUD comorbidity in inpatient treatment was examined at one year after treatment initiation. Insight in the network at one-year follow-up was of particular interest due to the high sparsity of the networks at seven-year follow-up. So, the exploratory analysis was carried out to investigate whether a difference in relations and connectedness exists due to the recency of the inpatient treatment effects after one year. The results highlight once more how influential the psychosocial and mental health factors are and strengthen the previous findings which present these factors as predisposing and perpetuating influences (Parmar & Kaloiya, 2018; Mee et al., 2019; Rasmussen et al., 2018). Furthermore, the results show a direct relation between contextual factors, specifically one's social context, and substance use. Taken together, these findings suggest that psychosocial and mental health factors indicate a risk for substance use especially when one's contextual factors are not curated.

**Limitations**

Our study has some limitations which should be considered when interpreting the results. First, the cross-sectional data investigated in this study does not allow causal conclusions, it only allows for hypotheses of causality. Also, the sample investigated in this study was taken from Norwegian treatment facilities, thus findings are not representative of other populations. Second, the accuracy and stability analyses made evident that the parameters in this study were estimated with moderate precision at best. Therefore, interpretation of networks at post-treatment is more sample-related than generalizable. The current study weighed a trade-off between sample size and time passed till the follow-up, and we opted for the seven-year follow-up data thereby compromising our sample size of the networks at post-treatment. Especially the sample size of the PD and Control networks was small due to missing data, which resulted in networks with unrelated nodes. We hope to replicate our findings in larger datasets of patients with SUD in inpatient treatment which will allow for inclusion of

more data from all variables of interest. Third, to accommodate the nominal, ordinal, and ratio measurement scales of the variables in the dataset the GGM was employed to estimate the networks in this study. Initially we intended to use the automatic estimation method in JASP, yet this resulted in non-positive definite matrices. Consequently, to solve this issue the Pearson correlation was applied as estimation method. Unfortunately, the Pearson correlation estimation yielded less connected networks. Moreover, perhaps a more fitting estimation would have been obtained by employing the mixed graphical model (MGM; Epskamp et al., 2017). The MGM accounts for the different types of measurement scales when computing the network and therefore yields a more accurate representation of the network and enables a more precise interpretation. Yet, this model is still in the developmental phase and is a promising method for the future. Finally, some of the baseline measures (e.g., abuse, education) show little variation in the Post-Treatment networks, which might have influenced the NCTs, reducing the power to detect differences between the networks. Also, the NCT might yield biased results if performed with unequal network sample sizes (van Borkulo et al., 2017), which was the case for our networks.

**Implications for Future Research**

Our study provides key insights regarding how contextual, psychosocial, and mental health factors are interrelated in the life of individuals in inpatient treatment for SUD. The next step for research will be to elucidate the dynamic effects between these factors in order to treat SUD more purposefully. Firstly, with respect to the final phase of treatment, reintegration into society, it is important to increase focus on strengthening the factors directly related to drug use (such as mental health, and an adaptive living situation) and their moderators (such as an occupation and income). Secondly, with respect to the difficulties in treating double diagnoses and their high prevalence, the most influential factors in treatment should be emphasized to safeguard recovery and prevent relapse. For instance, by dedicating more time to mental health and psychosocial factors in treatment of patients with PD-SUD comorbidity. Thus, it is important for future studies to test the suggestions generated based on the findings of the current study by employing a network intervention analysis in future longitudinal and experimental research.

Provided that contextual, psychosocial, and mental health factors play such a key role in the development of and recovery from SUD, improving our understanding of their interconnectivity and reciprocal influence is of crucial importance in the advancement of targeted and effective treatment programs.

## Conflicting Interests

The author declares no conflicting interests.

## Acknowledgements

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**Appendix A**

| | Variable | Measure | Item Label | Scale | Range |
|---|---|---|---|---|---|
| | Illicit drug use | Norwegian trans. EuropASI | Substance use during last 30 days | Ordinal | 0 (no use);<br>1 (use);<br>2 – 7 (polysubstance use) |
| | Alcohol use over threshold | Norwegian trans. EuropASI | Alcohol abuse during last 30 days | Nominal | 0 (no abuse);<br>1 (abuse) |
| Context-ual | Education | Norwegian trans. EuropASI | Years of education | Ratio | 0 – 15 years |
| | Work income | Norwegian trans. EuropASI | Money for support from work | Nominal | 0 (no); 1 (yes) |
| | Living situation | Norwegian trans. EuropASI | Living with person who uses alcohol or drugs | Ordinal | 0 (no);<br>1 (alcohol/drugs);<br>2 (alcohol and drugs) |
| | Primary school problems | Norwegian trans. EuropASI | Problems in elementary school | Nominal | 0 (no); 1 (yes) |
| | Welfare child services | Norwegian trans. EuropASI | Under supervision of child welfare services | Nominal | 0 (no); 1 (yes) |
| | Close friends | Norwegian trans. EuropASI | Number of close friends | Ratio | 0 – 15 friends |
| Psycho-social | Emotional abuse | CTQ | Statements about childhood circumstances | Ordinal | 0 (none to minimal);<br>1 (low to moderate);<br>2 (moderate to severe);<br>3 (severe to extreme) |
| | Physical abuse | CTQ | Statements about childhood circumstances | Ordinal | 0 (none to minimal);<br>1 (low to moderate);<br>2 (moderate to severe);<br>3 (severe to extreme) |
| | Sexual abuse | CTQ | Statements about childhood circumstances | Ordinal | 0 (none to minimal);<br>1 (low to moderate);<br>2 (moderate to severe);<br>3 (severe to extreme) |

| | | | | | |
|---|---|---|---|---|---|
| | Parental history drug use | Norwegian trans. EuropASI | Substantial alcohol/drug problem of mother/father | Nominal | 0 (no); 1 (mother/father); 2 (mother and father) |
| | Parental history mental health | Norwegian trans. EuropASI | Mental problem of mother/father | Nominal | 0 (no); 1 (mother/father); 2 (mother and father) |
| Mental Health | Anxiety | Self-report MCMI II | Cut-off score of 84 | Nominal | 0 (no); 1 (yes) |
| | Depression | Self-report MCMI II | Cut-off score of 84 | Nominal | 0 (no); 1 (yes) |
| | Cognitive difficulties | Self-report MCMI II | Cut-off score of 84 | Nominal | 0 (no); 1 (yes) |

Appendix A. Description and properties of measures included in network analysis.

## Appendix B

Accuracy and Stability Bootstraps of the Regularized Partial Correlation Networks

The edge-weight accuracy plots in this appendix show the bootstrapped CIs of the estimated edge-weights ($n$ = 1000) for each network. The black line indicates the mean of all bootstrapped edge-weights, the CIs are indicated by the gray area and the red line indicates the sample values.

Furthermore, the centrality stability plots in this appendix show the average correlations between the original sample and the centrality measures (betweenness, strength) of networks bootstrapped with case dropping ($n$ = 1000). The lines indicate the correlation means and their respective CIs are indicated by the colored area.

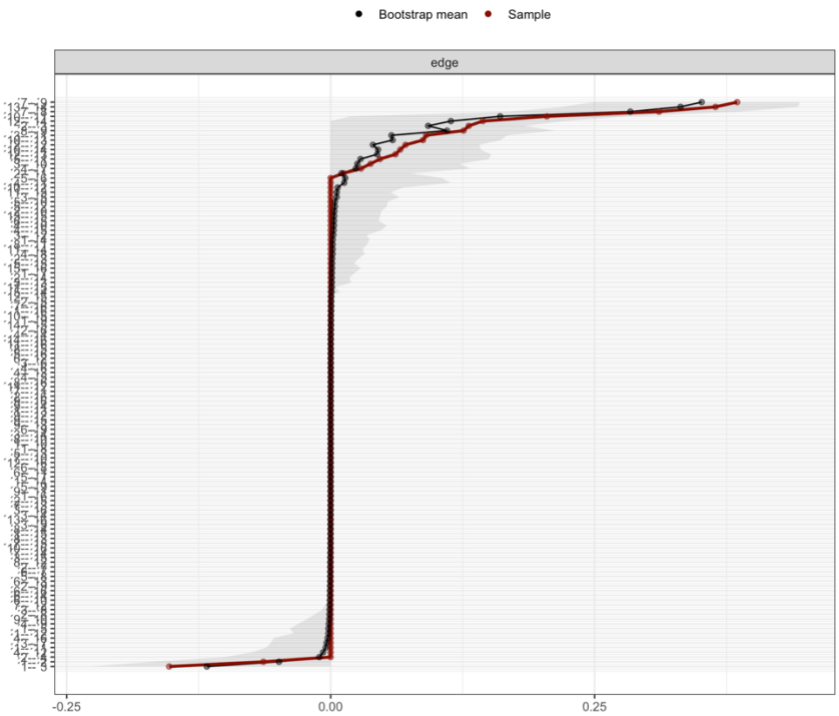


Figure B1. Edge-weight accuracy of Pre-Treatment Network

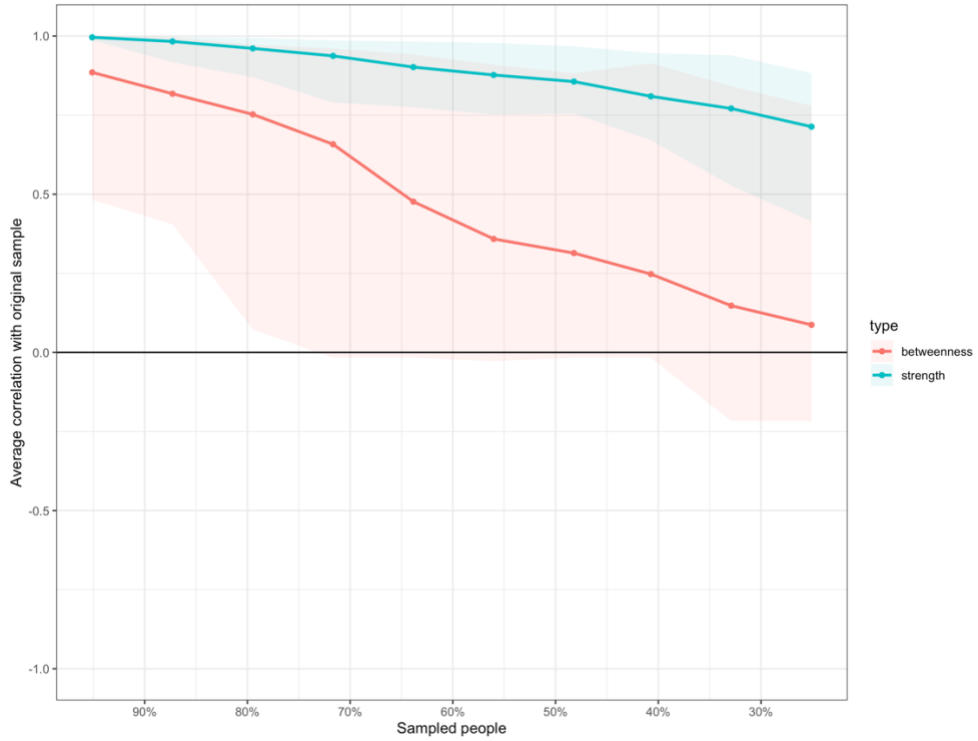


Figure B2. Centrality stability of Pre-Treatment Network

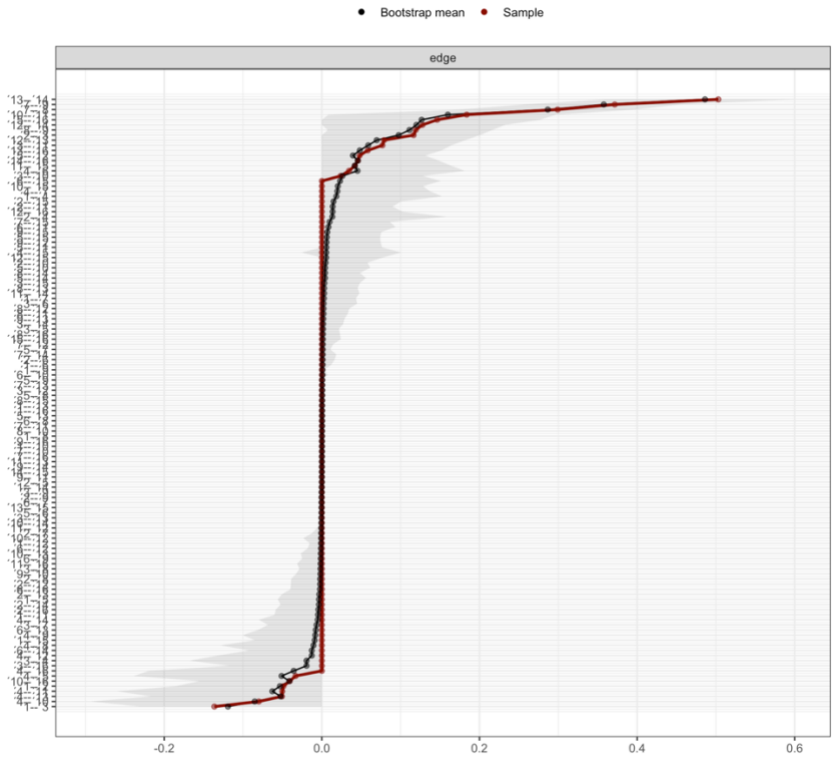


Figure B3. Edge-weight accuracy of Post-Treatment Network

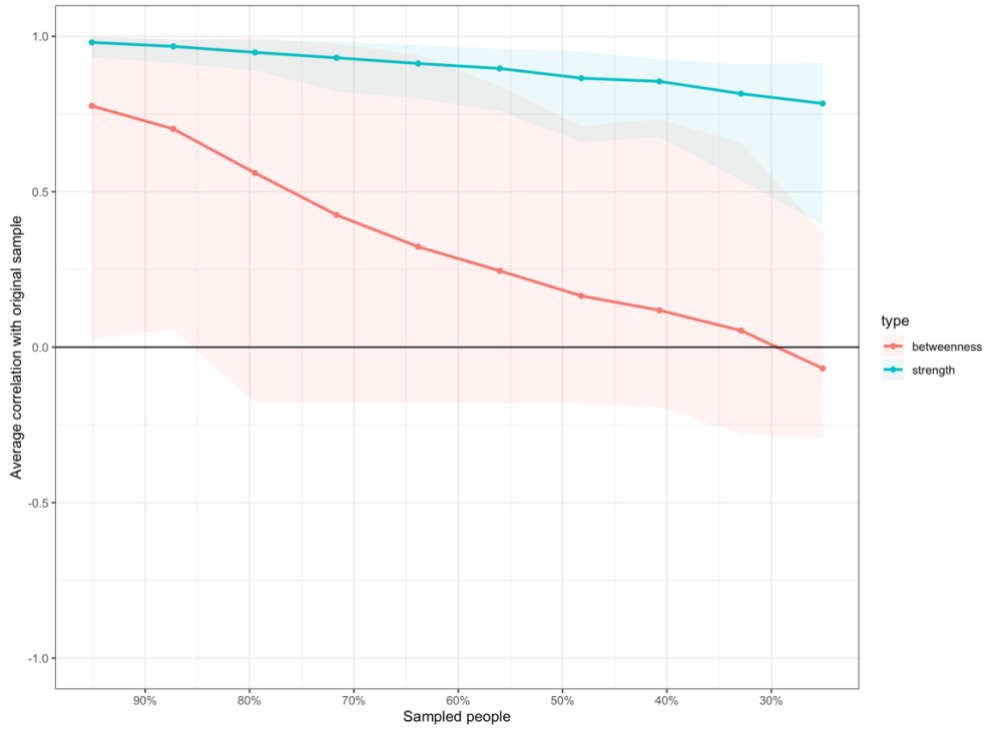


Figure B4. Centrality stability of Post-Treatment Network

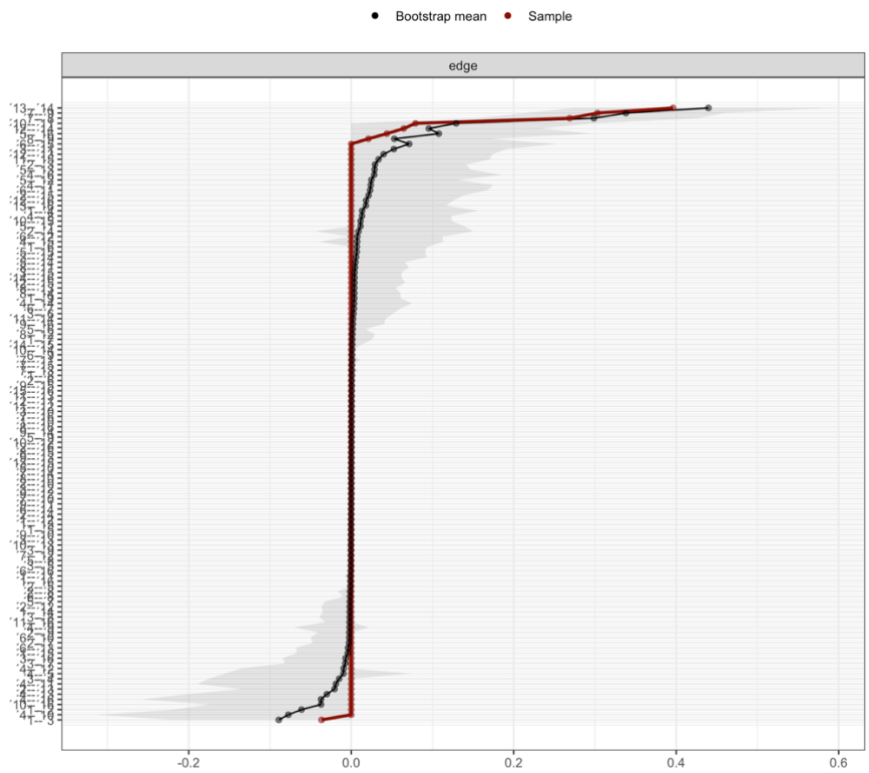


Figure B5. Edge-weight accuracy of PD Network

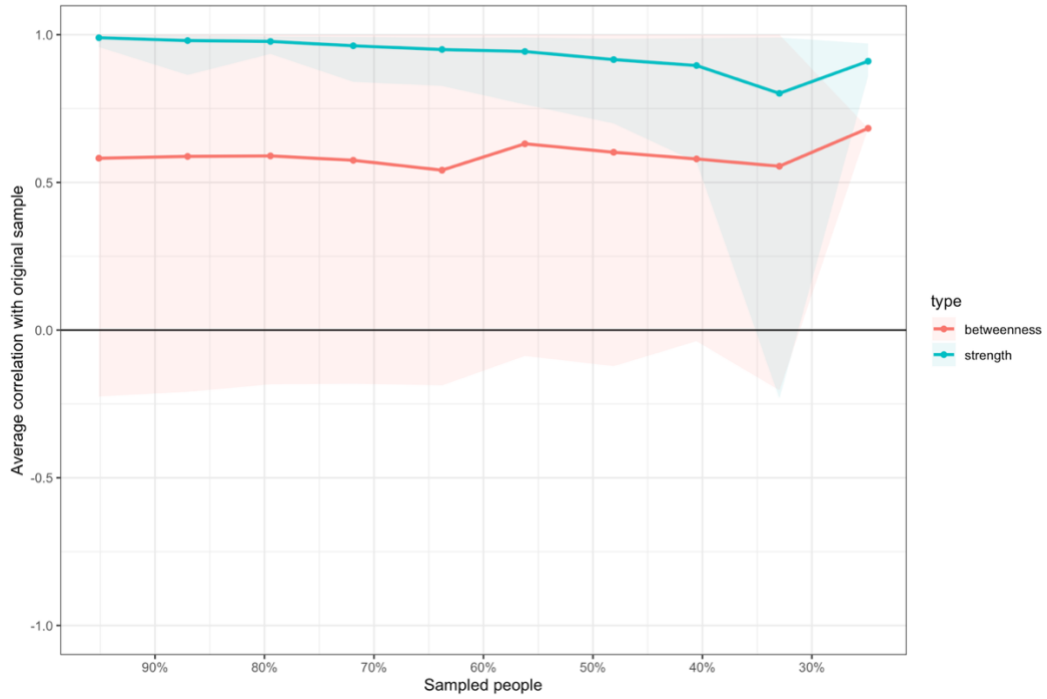


Figure B6. Centrality stability of PD Network

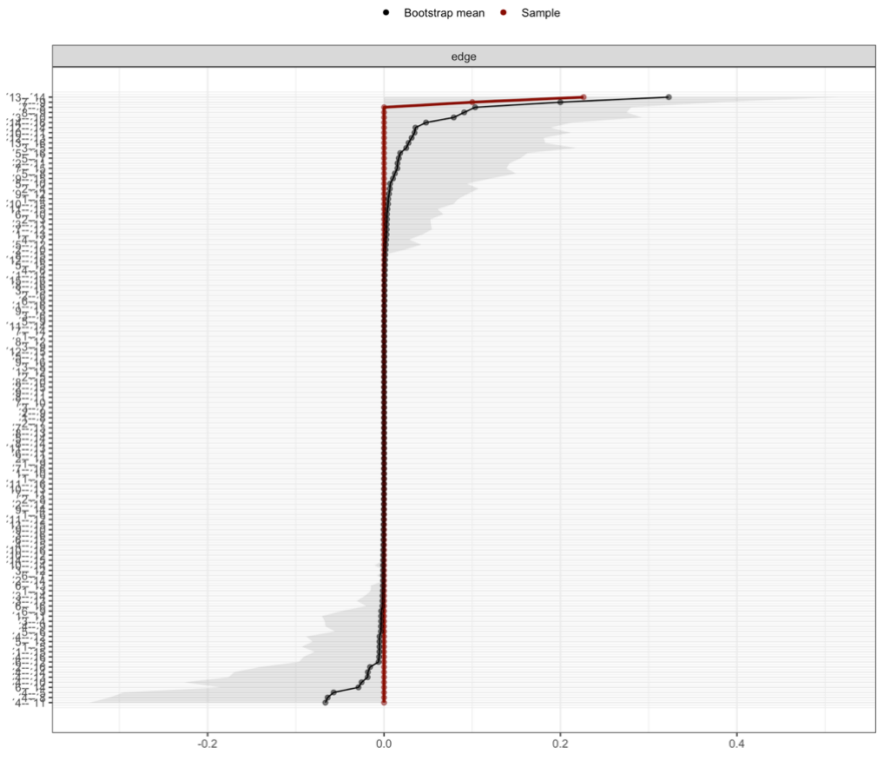


Figure B7. Edge-weight accuracy of Control Network

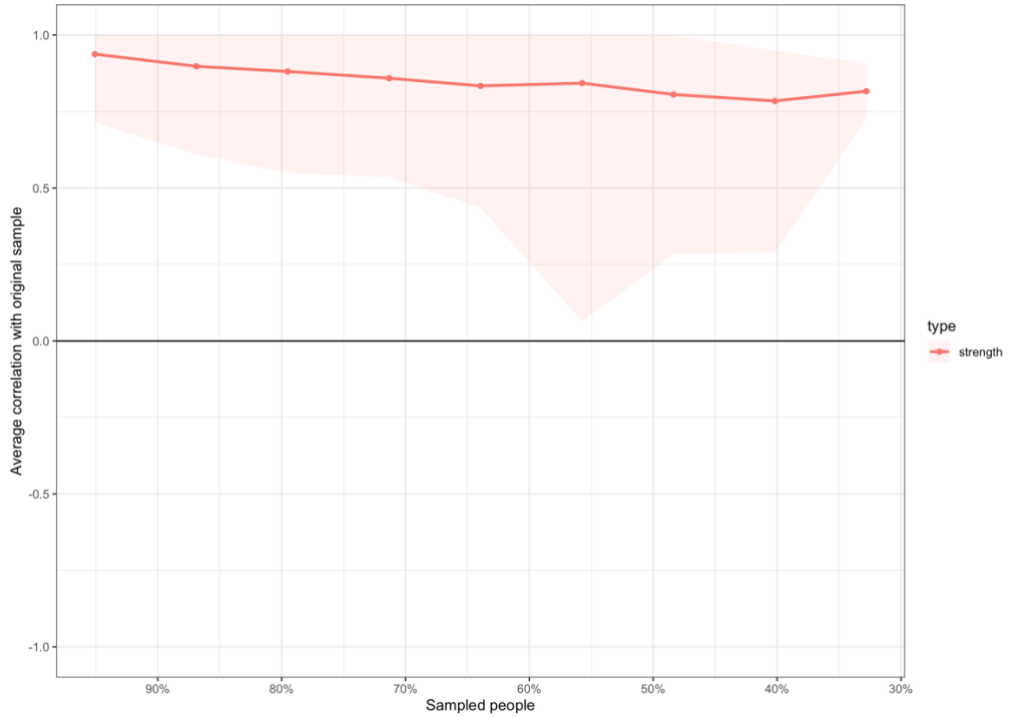


Figure B8. Centrality stability of Control Network

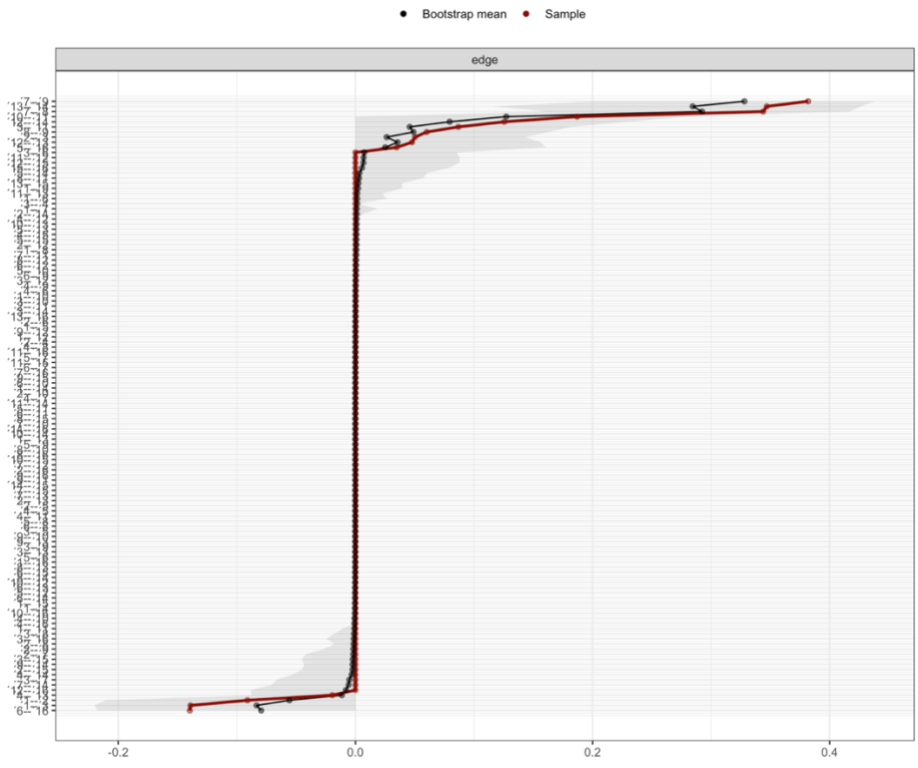


Figure B9. Edge-weight accuracy of PD Network at one-year follow-up

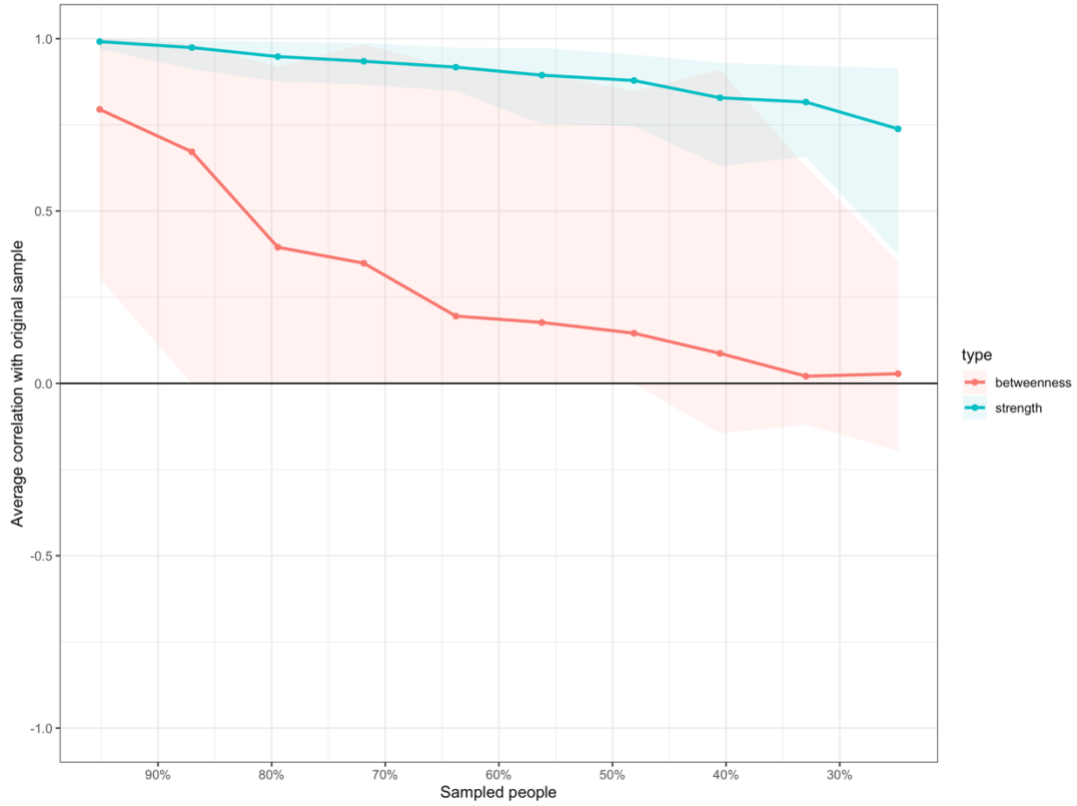


Figure B10. Centrality stability of PD Network at one-year follow-up