Pain Medicine, 2024, **25**, 231–238
https://doi.org/10.1093/pm/pnad148
Advance access publication 7 November 2023
Original Research Article

A network analysis of pain intensity and pain-related measures of physical, emotional, and social functioning in US military service members with chronic pain

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Abstract

Objective: The purpose of this study was to apply network analysis methodology to better understand the relationships between pain-related measures among people with chronic pain.

Methods: We analyzed data from a cross-sectional sample of 4614 active duty service members with chronic pain referred to 1 military interdisciplinary pain management center between 2014 and 2021. Using a combination of Patient-Reported Outcomes Measurement Information System measures and other pain-related measures, we applied the "EBICglasso" algorithm to create regularized partial correlation networks that would identify the most influential measures.

Results: Pain interference, depression, and anxiety had the highest strength in these networks. Pain catastrophizing played an important role in the association between pain and other pain-related health measures. Bootstrap analyses showed that the networks were very stable and the edge weights accurately estimated in 2 analyses (with and without pain catastrophizing).

Conclusions: Our findings offer new insights into the relationships between symptoms using network analysis. Important findings highlight the strength of association between pain interference, depression and anxiety, which suggests that if pain is to be treated depression and anxiety must also be addressed. What was of specific importance was the role that pain catastrophizing had in the relationship between pain and other symptoms suggesting that pain catastrophizing is a key symptom on which to focus for treatment of chronic pain.

Keywords: Chronic pain, pain-related measures, network analysis.

Introduction

Chronic pain, defined as persistent or recurrent pain lasting longer than 3 months,[1] is a significant health problem in the United States.[2] Among US active duty service members (ADSMs) there is an elevated risk for chronic pain due to the nature of military service and related job training.[3,4] Chronic pain is responsible for an estimated 261.1 medical encounters by ADSMs per 10 000 person-years[5] and is a leading cause of disability and medical discharge in the military, imposing significant burden on readiness and mission capabilities.[6–8] Therefore, ADSMs with chronic pain are an important population on which to focus.

As people with chronic pain often experience multiple comorbid conditions, it is important to view chronic pain not as just one symptom, but in relationship with co-occurring symptoms of other conditions.[1,9] Chronic pain often has bidirectional relationships with symptoms of a wide range of affective disorders, such as anxiety and depression as well as sleep deficiency.[10,11] In fact, existing studies support the understanding that the experience of chronic pain is influenced by a cluster of biopsychosocial factors (eg, anxiety, depression, anger, fatigue, sleep, physical function, and social roles).[1,12–15] These relationships highlight the importance of measuring and addressing not only pain intensity but also pain-related physical, emotional, and social functioning when caring for people with chronic pain.[16]

Network analysis is an analytic technique that provides graphical representations of the relationships (edges) between selected measures (nodes).[17] Network analysis provides summary metrics (centrality measures) that quantify the influence of one variable on others that may be potential targets for treatment.[18] Unlike bivariate correlation analysis, network analysis using partial correlations quantifies the relationships between variables after controlling for the influence of other variables in the model.[18] Recent studies of populations with chronic pain have reported that among the pain-related measures studied, depressive mood, fatigue, and pain interference had the most prominent correlations with chronic pain.[19,20] Gomez Penedo et al.,[21] who analyzed associations among depressive, anxiety, and pain in patients with chronic pain, showed that sleep problems were associated with pain intensity as well as with symptoms of both anxiety and depression.

Received: 8 May 2023. **Revised:** 20 October 2023. **Accepted:** 26 October 2023

However, despite the previous studies examining this symptom network in people with chronic pain,[18,19,21] there is still a lack of evidence regarding the associations between these factors and numerous other pain-related physical, emotional, and social factors, such as pain interference, pain catastrophizing, sleep, fatigue, and physical function.

The Pain Assessment Screening Tool and Outcomes Registry (PASTOR) is an electronic web-based battery of patient-reported outcomes (PROs) adapted from the National Institutes of Health's Patient-Reported Outcomes Measurement Information System (PROMIS) to provide comprehensive multi-domain evaluation of patients with chronic pain.[22,23] PASTOR is used at pain specialty clinics across the US Military Health System to allow for multidimensional assessment of patients with chronic pain.[22] Considering the numerous advantages of using PASTOR, including the standardized battery of assessment scales across many functional domains,[24] PASTOR data yield a rich opportunity to apply a network approach to gain a better understanding of the interrelationships between patient-reported health measures and chronic pain. However, to date no previous network analyses of psychological/social factors and pain related outcomes in a military population has been conducted. Thus, among ADSMs with chronic pain this study aimed to: (1) use network analysis to examine the associations between measures of physical, emotional, and social function ($N = 4231$) and (2) in a subset of ADSMs with chronic pain ($n = 1237$), explore the relationship of symptoms when pain catastrophizing was added to the network.

Methods

Setting and sample

This was a cross-sectional study using secondary data analyses from a tertiary-care military treatment facility. ADSMs with chronic pain referred to one military interdisciplinary pain management center between 2014 and 2021 completed PASTOR assessments. A total of 4614 participants who completed at least 1 PASTOR assessment were included in the analyses. This study was approved by the Regional Health Command—Pacific Institutional Review Board (protocol no. 218052). Because data were deidentified prior to analysis, a waiver of informed consent was granted.

Measures

Demographic characteristics

Demographic characteristics analyzed included participants' age group, biological sex (as male or female), race, education level, marital status, and household income.

Patient-Reported measures included in PASTOR

All patient-reported measures included in PASTOR have established validity and reliability and have been validated in the military population.[22,23,25,26]

Defense and Veterans Pain Rating Scale. The Defense and Veterans Pain Rating Scale is a self-report questionnaire that assesses pain intensity in military service members by using visual cues and word descriptors to anchor pain ratings with perceptual experiences and limitations imposed by pain.[27] Average pain intensity over the previous 7 days is rated using an 11-point numeric rating scale from 0 ("No pain") to 10 ("As bad as it could be, nothing else matters").[27]

Pain Catastrophizing Scale. The Pain Catastrophizing Scale is a 13-item self-report questionnaire that assesses negative cognitive affective response to anticipated or actual pain.[28] Participants are asked to reflect on past painful experiences and indicate the degree to which they experience each of 13 thoughts and feelings when they are in pain.[28] It uses a 5-point scale, ranging from 0 ("Not at all") to 4 ("All the time"). The total score ranges from 0 to 52, with higher scores representing greater catastrophic thinking.[28]

Patient-Reported Outcomes Measurement Information System measures. The 8 PROMIS measures included in PASTOR are anger, anxiety, depression, fatigue, pain interference, physical function, satisfaction with social roles, and sleep-related impairment.[29–31] Computer adaptive testing is used to reduce the survey burden. The total score for each is converted to a *T*-score with a mean of 50 and a standard deviation of 10 for the referent general US population; a higher PROMIS *T*-score represents a stronger association with the concept being measured. The PROMIS measures have been validated in a broad sample of individuals living with chronic conditions.[22]

Statistical analysis

Descriptive statistics were examined for the demographic variables and PASTOR measures. We then conducted network analyses using qgraph and bootnet packages within the statistical platform R[32,33] and applied a regularized partial correlation network using the "EBICglasso" algorithm to identify the most influential or central outcome measures (nodes) and associations between those outcome measures (edges). *Nodes* correspond to the variables included in the model and are shown as labeled ovals in the network diagrams. *Edges* are the lines between the nodes, which correspond to partial correlations between variables. *Strength* refers to the overall relationship of each node to other nodes in the model and is indicated by the width of the edge that links them, with thicker edges representing stronger partial correlations. The color of the edges indicates the direction of the association between nodes, with blue edges indicating positive correlation and red edges indicating negative correlation.

The density of a network is a measure of the number of associations between nodes out of all possible associations, with a high density indicating a high degree of interrelatedness between nodes (measures).[34] Centrality indices (closeness, betweenness, and strength) were calculated at local levels to identify the importance of each node in the network. *Closeness* refers to the distance between 1 node and all other nodes within the network, with higher closeness indicating greater influence.[35] *Betweenness* is a measure of how much 1 node in the model works as a bridge between 2 other nodes that are not directly related to one another.[35] *Strength* is the sum of the weighted number and strength of all connections of a specific node relative to all other nodes.[35] Strength index identifies which nodes may potentially maintain interactions within and between nodes, and which nodes may be potential targets for intervention.[36] In our analysis, the nodes with the highest centrality indices were identified as the central measures. Standardized *z*-scores are plotted for centrality plots. Higher score represent higher centrality estimates (ie, the measures have greater influence in the network).

The robustness of the network was analyzed by a bootstrap analysis ($N = 10\,000$ iterations), using nonparametric bootstrapping to assess the accuracy of network estimation and

case-dropping subsets to assess the stability of centrality indices. To gain insights into the accuracy of edge weights in the estimated network structure, we bootstrapped 95% confidence intervals around the edge weights.[33] In terms of the stability of centrality indices, the correlation-stability coefficient represents the maximum proportion of participants that can be dropped while maintaining 95% probability that the correlation between centrality metrics from the full data set and the subset data is at least 0.7.[37] A correlation-stability coefficient higher than 0.25, and preferably above 0.5, is recommended for interpreting centrality indices.[33]

First, we investigated associations between pain intensity and the 8 PROMIS measures of pain-related physical, emotional, and social functioning (anger, anxiety, depression, fatigue, pain interference, physical function, satisfaction with social roles, and sleep-related impairment) in ADSMs with chronic pain ($N = 4231$), including only valid data. Second, because the Pain Catastrophizing Scale was added to the assessment tool midway through the data collection period, we ran a separate exploratory network analysis with a smaller sample size ($n = 1237$) between these same measures but including the Pain Catastrophizing Scale.

Results

Descriptive statistics

A total of 4614 ADSMs with chronic pain were included in the analysis. The demographic subgroups with the highest representation were male (77.5%), older than 35 years (46%), White (47.5%), and married (73%). Details regarding age categories, including any missing data, along with participants' demographics and mean scores on the PASTOR measures, can be found in Table 1.

Network estimation

In the first analysis, Figure 1A shows the network structure of the correlations between 9 measures. The density of the network was high (density = 0.81, 29/36), indicating that most measures in the model were related to one another. The central plot (Figure 1B) revealed that the measures with the strength—indicating high importance to the model—were pain interference, anxiety, depression, sleep impairment, and fatigue. Satisfaction with social roles, pain interference, and depression had the highest betweenness (ie, stronger bridging effect between 2 measures that are not directly related) and closeness (ie, stronger influence on other nodes). The strongest edges within the network were the edges between anxiety and depression; sleep impairment and fatigue; pain intensity and pain interference; and pain interference and physical function.

In the second analysis (Figure 2), which included pain catastrophizing, the density of the network was also high (density = 0.76, 34/45), and the results were similar to those in the first analysis with regard to the direction and strength of correlations between variables. The addition of pain catastrophizing to the second model revealed that pain catastrophizing surpassed satisfaction with social roles in level of betweenness and closeness. This indicates that pain catastrophizing has strong direct links to other measures, as well as serving as a bridge between other measures that are not directly related to another.

Table 1. Sample characteristics and mean PASTOR measure scores ($N = 4614$).

Variables		Mean (SD) or *n* (%)
Sex	Male	3576 (77.5)
	Female	1034 (22.4)
	Missing	4 (0.1)
Age (in years)[a]		
Data set A ($n = 1902$)	18–24	317 (16.7)
	25–34	754 (39.6)
	35–44	601 (31.6)
	45–64	227 (11.9)
	65–84	3 (0.2)
Data set B ($n = 2712$)	18–24	368 (13.6)
	25–29	525 (19.4)
	30–34	528 (19.5)
	35–39	478 (17.6)
	40 ≤	813 (30)
Race	White	2191 (47.5)
	Black	546 (11.8)
	Asian/Pacific Islander	461 (10)
	Other	394 (8.5)
	Missing	1022 (22.1)
Education	Some high school/High school graduation/GED or less	1056 (22.9)
	Some college/Technical degree	2200 (47.7)
	College degree (BA, BS)	836 (18.1)
	Advanced degree (MA, PhD, MD)	449 (9.7)
	Missing	73 (1.6)
Marital status	Single	662 (14.3)
	Married	3367 (73)
	Divorced	315 (6.8)
	Domestic partnership	23 (0.5)
	Separated	143 (3.1)
	Widowed	21 (0.5)
	Missing	83 (1.8)
Income	≤ $20 000	158 (3.4)
	$20 000–$49 999	1555 (33.7)
	$50 000–$99 999	1717 (37.2)
	≥ $100 000	598 (12.9)
	Prefer not to answer	504 (12.8)
DVPRS	Average pain intensity in past 7 days (0–10) ($n = 4593$)	5.7 (1.6)
Pain catastrophizing	Pain catastrophizing scale (0–52) ($n = 1461$)	21.4 (13.8)
PROMIS *T*-score	Pain interference ($n = 4514$)	65.1 (5.8)
	Physical function[b] ($n = 4507$)	39.5 (6.2)
	Fatigue ($n = 4497$)	59.6 (9.7)
	Anxiety ($n = 4463$)	55.9 (10.7)
	Depression ($n = 4471$)	52.9 (10.7)
	Anger ($n = 4454$)	54.7 (11.6)
	Sleep-related impairment ($n = 4484$)	61.1 (9.9)
	Satisfaction with social roles[b] ($n = 4238$)	39.3 (7.8)

[a] The age categories are sourced from 2 distinct data sets. Due to variations in the age categorization across these data sets, both categories have been retained to offer an overview of the age distribution within our study population.

[b] PROMIS measure with positively worded concept.

DVPRS, Defense and Veterans Pain Rating Scale; PASTOR, Pain Assessment Screening Tool and Outcomes Registry; PROMIS, Patient-Reported Outcomes Measurement Information System; SD, standard deviation.

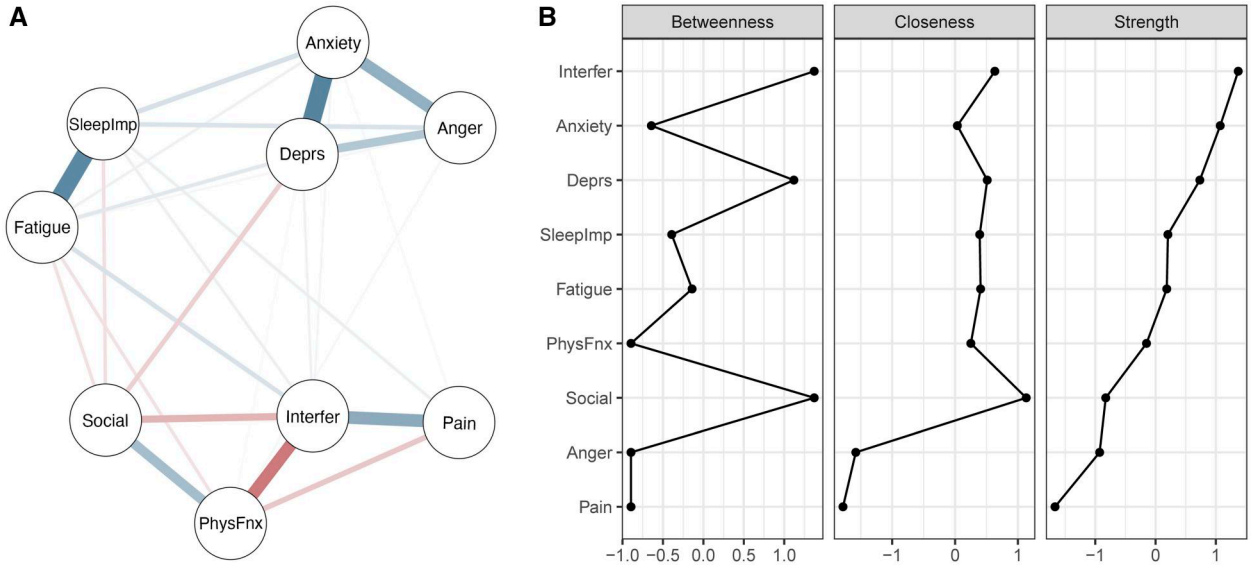

Figure 1. Network structure and centrality plot, excluding pain catastrophizing ($N = 4231$). (**A**) Network structure. (**B**) Centrality estimates. Pain = pain intensity; Interfere = pain interference; PhysFnx = physical function; Deprs = depression, SleepImp = sleep-related impairment; Social = satisfaction with social roles. Blue lines represent positive associations; red lines represent negative associations. Heavier lines (edges) between measures (nodes) in the network indicate stronger partial correlations between the measures.

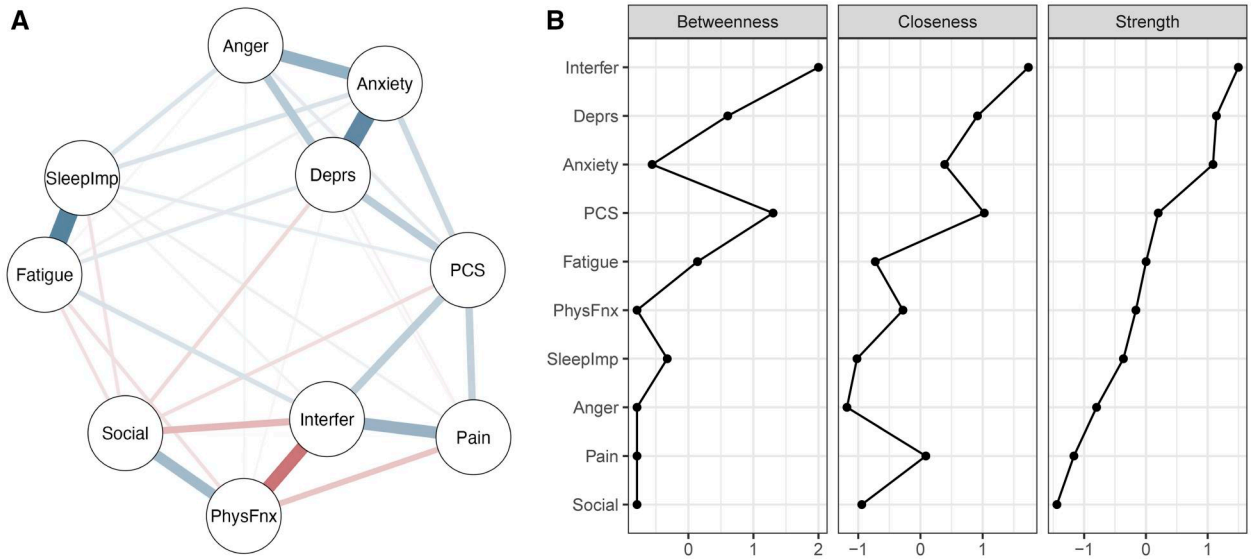

Figure 2. Network structure and centrality plot, including pain catastrophizing ($N = 1237$). (**A**) Network structure. (**B**) Centrality estimates. Pain = pain intensity; Interfere = pain interference; PhysFnx = physical function; Deprs = depression, SleepImp = sleep-related impairment; Social = satisfaction with social roles; PCS = pain catastrophizing. Blue lines represent positive associations; red lines represent negative associations. Heavier lines (edges) between measures (nodes) in the network indicate stronger partial correlations between the measures.

Network accuracy and stability

We conducted the classical bootstrap methods to examine the accuracy and stability of the network analyses (see Figures 3 and 4). The accuracy of network estimation provides good strap confidence intervals; smaller confidence intervals indicate a more accurate estimation of edge weights. The stability of centrality was good, with correlation-stability coefficient higher than 0.75 in both analyses.

Discussion

To the best of our knowledge, this is the first study to use network analysis to examine symptom relationships among ADSMs with chronic pain. Chronic pain is associated with a complex interplay of physical, emotional, and social factors. In both of our analyses, whether including 9 or 10 measures, we found that pain interference, depression, anxiety were the measures with the highest strength centrality among the variables included in the network. This finding is similar to those of previous studies examining the symptom network of chronic pain in other populations[19,21] and will come as no surprise to health professionals who care for people with chronic pain, who often present with these comorbid concerns. This study's findings also support previous findings by providing an understanding of which of these measures are directly or indirectly related through mediators, and which measures are most influential in the network of

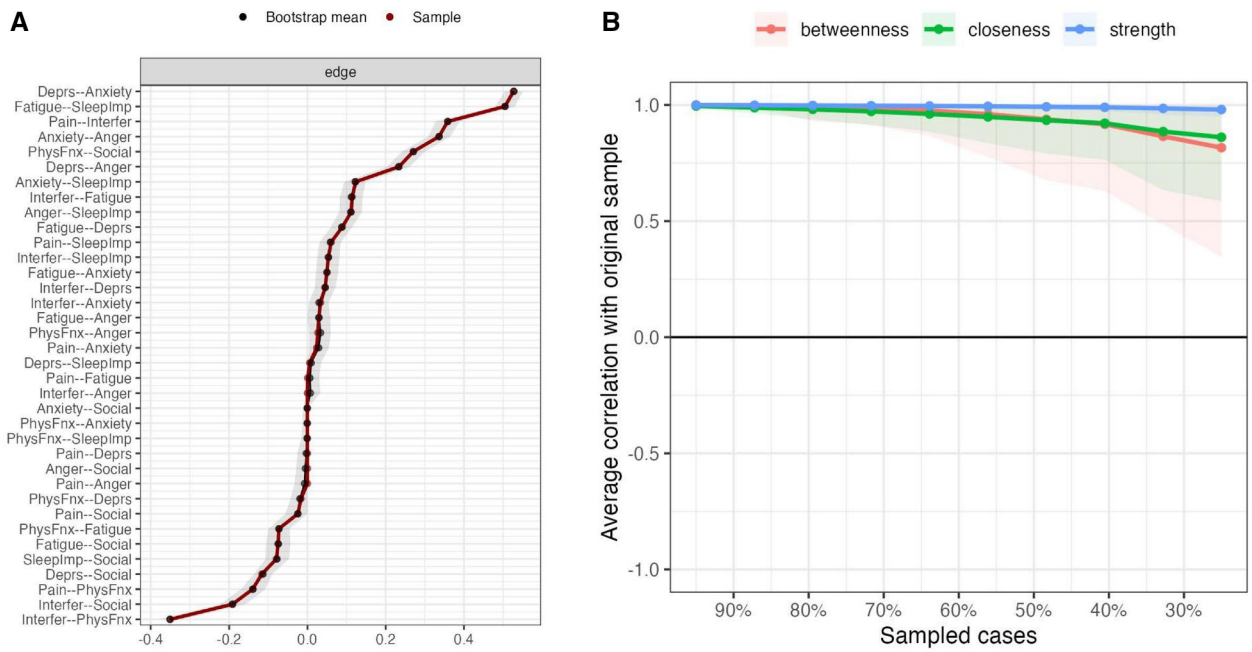

Figure 3. Network accuracy and stability, excluding pain catastrophizing ($N = 4231$). (**A**) Edge weights (solid line) and the 95% confidence intervals around these edge weights (gray bars). Each horizontal line represents 1 edge of the network (The edges are ordered from the highest edge-weight to the lowest edge-weight.). (**B**) Correlation of the centrality of nodes in terms of betweenness, closeness, and strength in the original network, with the centrality of networks sampled while dropping participants. A correlation coefficient higher than 0.25 is recommended for interpreting centrality indexes.

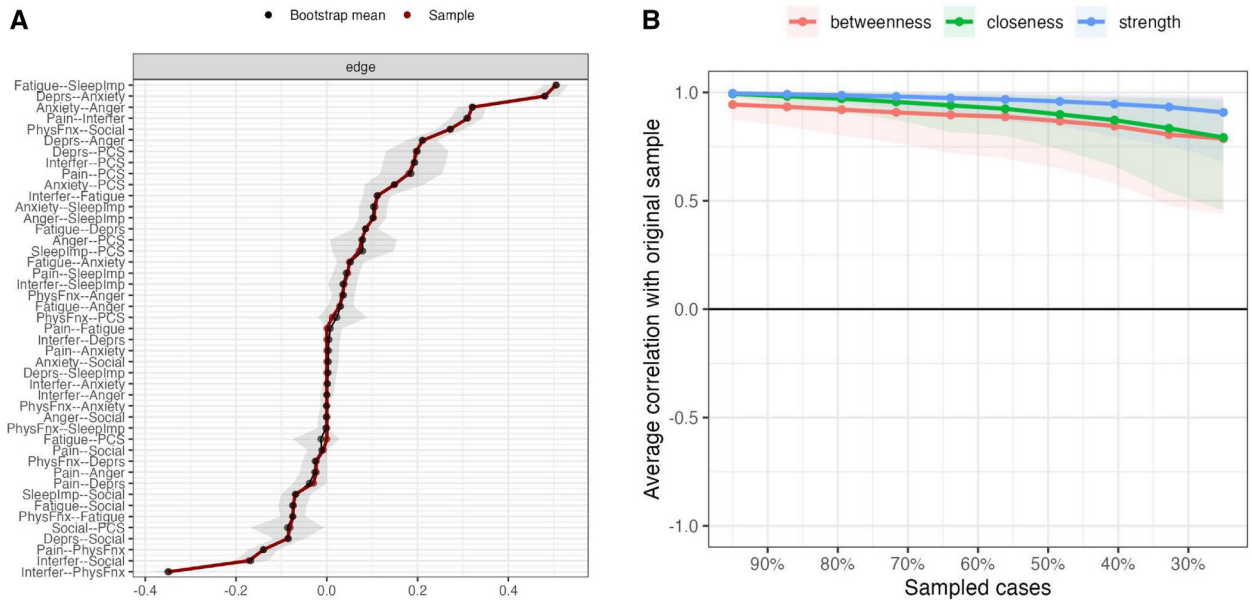

Figure 4. Network accuracy and stability, including pain catastrophizing ($N = 1237$). (**A**) Edge weights (solid line) and the 95% confidence intervals around these edge weights (gray bars). Each horizontal line represents 1 edge of the network (The edges are ordered from the highest edge-weight to the lowest edge-weight.). (**B**) Correlation of the centrality of nodes in terms of betweenness, closeness, and strength in the original network, with the centrality of networks sampled while dropping participants. A correlation coefficient higher than 0.25 is recommended for interpreting centrality indices.

chronic pain.[38] This information will assist clinicians caring for ADSMs with chronic pain by emphasizing the need to focus on symptoms that co-occur rather than 1 specific symptom.

Satisfaction with social roles

Our first analysis, which excluded pain catastrophizing, produced results demonstrating that satisfaction with social roles had the highest betweenness and closeness among the included measures. These findings support the previous literature by identifying the mediating effect of satisfaction with social roles between pain intensity and emotional symptoms such as anger and depression.[39] This study thus highlights the importance of including satisfaction with social roles as a treatment target for improving pain-related physical and emotional functioning, and supports attempts to return people with chronic pain to valued social engagements.[39] It is also interesting that satisfaction with social roles was more

closely connected to pain interference than the mood measures (anxiety/depression) or the sleep/fatigue, and that it has relatively little edge with the pain catastrophizing score. This may be because chronic pain often interferes with social engagement by leading people to withdrawal from activities with loved ones and peers, leading to progressively worsening social isolation.

Pain catastrophizing

However, our second analysis revealed that pain catastrophizing had even greater betweenness in the network than satisfaction with social roles. This indicates that pain catastrophizing serves as a bridge between other variables. What is of particular interest is that there were rather minimal edges between the anxiety and depression and pain, and that the addition of pain catastrophizing provided a strong link to anxiety, depression and pain that then surpassed social roles in level of betweenness and closeness. This finding could be explained by people interpreting pain as harmful (ie, pain catastrophizing), leading to subsequent pain-associated fear and anxiety, resulting in maladaptive emotion processing, and contributing to greater challenges with pain management.[40] It also could be that ADSMs with high anxiety and depression may tend to develop pain catastrophizing when exposed to chronic pain.

Our analyses are consistent with the findings of previous studies, which identify the mediating role of pain catastrophizing between pain and emotional distress such as anxiety and depression.[41–43] Thus, our findings highlight the importance of understanding the impact of pain catastrophizing in chronic pain management.

Sleep-related impairment

Sleep deficiency is both common among ADSMs and commonly associated with pain-related functioning.[44] The present study's findings are consistent with previous literature regarding the positive association between sleep and pain[45] but extend previous findings by identifying "sleep-related impairment" (ie, sleepiness, tiredness, and functional impairments during waking hours associated with sleep problems) as a central measure with high strength in the network of chronic pain. Recent research has highlighted the importance of improving sleep along with depressive and anxious symptoms to impact pain reduction.[46] This finding indicates that sleep-related impairment should be routinely measured and targeted for intervention by health care providers treating people with chronic pain. Future research remains necessary to gain a deeper understanding of the role of sleep on the symptom network of chronic pain by including both objective and subjective measurements of sleep.

Clinical implications

Network analysis provides a novel approach for pain management by providing information about highly interconnected pain-related factors and the associations between them, and by identifying targets for effective interventions.[47] Highly central measures are related to other measures in a network, which may influence the level of overall impairment.[48] Our study findings identified several significant relationships among pain-related outcomes which could have important clinical implications for the management of chronic pain[49] and clarified the relationships between pain intensity and measures of physical, emotional and social functioning in people with chronic pain. Our findings emphasized the essence of a holistic therapeutic approach, suggesting that to manage pain effectively, the concurrent management of depression and anxiety is important.[50] Interventions that address pain interference, depression, anxiety, sleep, and pain catastrophizing may help to relieve chronic pain. Particularly noteworthy was the significant role of pain catastrophizing in influencing the relationship between pain and other symptoms, pointing to it as a crucial focus in the treatment strategies for chronic pain.

Strengths and limitations

The strengths of this study include a sample size of ADSMs with chronic pain large enough to establish the accuracy and stability of the network models and the use of PROMIS measures, including common data elements encouraged for clinical research in pain management.[51] Network analysis is an innovative statistical approach that enhances our understanding of the associations between measures of physical, emotional, and social functioning in people with chronic pain. From a clinical perspective, a network model for investigating symptomatology has value because symptoms do not occur in isolation;[52] thus, treatment for chronic pain can be developed based on the most influential symptoms in a network.[13,21] As PROMIS enables efficient and interpretable clinical trial and clinical practice applications of patient-reported outcomes,[24] the findings of this study can be compared with the results of future clinical studies in pain management.

Alongside the results of this study, the following limitations should be considered. First, our study predominantly included male ADSMs with chronic pain; therefore, making broad generalizations to other chronic pain populations should be done with caution. However, focusing on the ADSM population is important, as it allows for a detailed exploration of pain within a group that has an elevated risk of chronic pain. Second, causal inference among measures could not be examined, due to the characteristics of cross-sectional study design. Future longitudinal studies exploring the network structure of pain-related measures in people with chronic pain will facilitate the understanding of causal influences between measures in the network.

Conclusion

Our findings provide evidence that pain-related measures of physical, emotional, and social functioning among people with chronic pain can be considered as a network with complex interrelationships. In particular, we identified pain catastrophizing as a potentially important target of intervention in chronic pain, especially among those with comorbid affective disorders. Researchers should also consider examining changes in network structure before and after interventions to explore the effectiveness of the interventions on outcomes of interest. Clinicians are encouraged to include routine assessment of the measures identified in this analysis—specifically, pain interference, depression, anxiety, sleep, and pain catastrophizing for people with chronic pain.

Acknowledgments

Disclaimer: The views expressed are those of the authors and do not reflect the policy or position of the Department of the

Army, Department of Defense, National Institutes of Health or US Government. The content is solely the responsibility of the authors. The investigators adhered to the policies for protection of human subjects as prescribed in 45 CFR 46. No nonhuman animal species were used in the conduct of this research.

Funding

The authors acknowledge funding from the National Institute of Health/National Institute of Neurological Disorders and Stroke (K24 AT011995, PI: AZD).

Conflicts of interest: The authors have no conflict of interest to declare.

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