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Network analysis of COVID-19-related PTSD symptoms in China: the similarities and differences between the general population and PTSD sub-population

Fan Yang[a], Mingqi Fu[b], Ning Huang[a], Farooq Ahmed[c,d], Muhammad Shahid[e], Bo Zhang[f], Jing Guo[a] and Paul Lodder[g]

[a]Department of Health Policy and Management, School of Public Health, Peking University Health Science Center, Beijing, P.R. China; [b]Center for Social Security Studies, Wuhan University, Wuhan, P.R. China; [c]Department of Anthropology, Quaid-i-Azam University, Islamabad, Pakistan; [d]Department of Anthropology, University of Washington, Seattle, WA, USA; [e]School of insurance and Economics, University of international business and economics, Beijing, P.R. China; [f]Department of Neurology and ICCTR Biostatistics and Research Design Center, Boston Children's Hospital, Harvard Medical School, Boston, MA, USA; [g]Department of Methodology and Statistics, Tilburg University, Tilburg, The Netherlands

ABSTRACT

Background and Objectives: Prevalent Post-traumatic Stress Disorder (PTSD) negatively affected individuals during the COVID-19 pandemic. Using network analyses, this study explored the construct of PTSD symptoms during the COVID-19 pandemic in China to identify similarities and differences in PTSD symptom network connectivity between the general Chinese population and individuals reporting PTSD.

Methods: We conducted an online survey recruiting 2858 Chinese adults. PTSD symptoms were measured using the PCL-5 and PTSD was determined according to the DSM-5 criteria.

Results: In the general population, self-destructive/reckless behaviours were on average the most strongly connected to other PTSD symptoms in the network. The five strongest positive connections were found between 1) avoidance of thoughts and avoidance of reminders, 2) concentration difficulties and sleep disturbance, 3) negative beliefs and negative trauma-related emotions, 4) irritability/anger and self-destructive/reckless behaviours, and 5) hypervigilance and exaggerated startle responses. Besides, negative connections were found between intrusive thoughts and trauma-related amnesia and between intrusive thoughts and self-destructive/reckless behaviours. Among individuals reporting PTSD, symptoms such as flashbacks and self-destructive/reckless behaviours were on average most strongly connected to other PTSD symptoms in the network. The five strongest positive connections were found between 1) concentration difficulty and sleep disturbance, 2) intrusive thoughts and emotional cue reactivity, 3) negative beliefs and negative trauma-related emotions, 4) irritability/anger and self-destructive/reckless behaviour, and 5) detachment and restricted affect. In addition, a negative connection was found between intrusive thoughts and self-destructive/reckless behaviours.

Conclusion: Our results indicate similarly positive connections between concentration difficulty and sleep disturbance, negative beliefs and negative trauma-related emotions, and irritability/anger and self-destructive/reckless behaviours in the general and PTSD-reported populations. We argue that self-destructive/reckless behaviours are a core symptom of COVID-19 related PTSD, worthy of more attention in future psychiatric programmers.

HIGHLIGHTS
• The most central symptom for the general group was self-destructive/reckless behaviours and for the PTSD subgroup was flashbacks.
• Results matched the hybrid model of PTSD and were important for prevention and intervention for PTSD related to COVID-19.

Analisis de redes de los sintomas de TEPT relacionados con COVID-19 en China: similitudes y diferencias entre la poblacion general y la subpoblacion con TEPT

Antecedentes y Objetivos: El Trastorno de Estrés Postraumático (TEPT) prevalente afectó negativamente a los individuos durante la pandemia del COVID-19. Usando análisis de redes, este estudio exploró el constructo de síntomas de TEPT durante la pandemia de COVID-19 en China para identificar las similitudes y diferencias en la conectividad de red de síntomas de TEPT entre la población general china y los individuos que reportan TEPT.

Métodos: Realizamos una encuesta en línea que reclutó 2.858 adultos chinos. Los síntomas de TEPT se midieron usando el PCL-5 y el TEPT se determinó de acuerdo a los criterios del DSM-5.

Resultados: En la población general, las conductas autodestructivas/ imprudentes fueron, en promedio, las más fuertemente conectadas con otros síntomas de TEPT en la red. Las cinco conexiones positivas más fuertes se encontraron entre 1) evitación de pensamientos y evitación de recordatorios, 2) dificultades en la concentración y trastornos del sueño, 3)

creencias negativas y emociones negativas relacionadas con el trauma, 4) irritabilidad/ ira y conductas autodestructivas/ imprudentes y 5) hipervigilancia y respuestas de sobresalto exageradas. Además, se encontraron conexiones negativas entre pensamientos intrusivos y amnesia relacionada con el trauma y entre pensamientos intrusivos y conductas autodestructivas/ imprudentes. Entre los individuos que reportaron TEPT, los síntomas como flashbacks y conductas autodestructivas/ imprudentes estuvieron, en promedio, más fuertemente conectadas con otros síntomas de TEPT en la red. Las cinco conexiones positivas más fuertes se encontraron entre 1) dificultades en la concentración y trastornos del sueño, 2) pensamientos intrusivos y reactividad emocional a ciertas señales, 3) creencias negativas y emociones negativas relacionadas con el trauma, 4) irritabilidad/ ira y conductas autodestructivas/ imprudentes, y 5) desapego y afecto restringido. Además, se encontró una conexión negativa entre pensamientos intrusivos y conductas autodestructivas/ imprudentes.
Conclusión: Nuestros resultados indican conexiones igualmente positivas entre dificultades en la concentración y trastornos del sueño, creencias negativas y emociones negativas relacionadas con el trauma, e irritabilidad/ ira y conductas autodestructivas/ imprudentes en la población general y la que reporto TEPT. Argumentamos que las conductas autodestructivas/imprudentes son un síntoma central de TEPT relacionado con COVID-19, que merece más atención en futuros programas psiquiátricos.

新冠疫情相关创伤后应激症状的网状结构分析: 基于中国普通人群和症状人群的对比研究

背景和目标: 创伤后应激障碍 (PTSD) 作为新冠全球大流行下发病较高的疾病, 给人们带来持续的痛苦体验, 警醒等负面影响。然而, 目前缺乏大样本下讨论 PTSD 症状之间的联系和其核心症状的研究, 且没有比较普通人群和达到诊断标准人群的症状学差异。因此, 本研究旨在通过网络分析揭示在不同人群中的新冠相关的 PTSD 症状间的联系, 并标记出其潜在的核心症状。

方法: 通过网络调查收集到 2858 个年龄在 18 岁及以上的有效样本, 并根据 DSM-5 的评价标准将样本中达到诊断标准的人群标记为 PTSD 人群。

结果: 在所有人群的症状学分析中, 避免思考和避免提醒; 难以集中注意力和睡眠障碍; 消极信念和消极的创伤相关情绪; 易怒/愤怒和自毁/鲁莽行为; 过度警觉和夸大惊吓反应之间存在很强的联系。侵入性思维与创伤相关健忘症; 侵入性的想法和自我毁灭/鲁莽的行为之间存在负相关。此外, 我们强调自毁/鲁莽行为是最核心的症状, 也是群体治疗和预防过程中的一个重要目标。在符合 PTSD 诊断标准人群的症状学分析中, 注意力不集中和睡眠障碍; 侵入性想法和情绪暗示反应; 消极信念和消极的创伤相关情绪; 易怒/愤怒和自毁/鲁莽行为存在强相关。此外, 分离和受限的情感, 以及侵入性思想和自我毁灭/鲁莽行为之间存在负向联系。我们强调, 针对 PTSD 人群的干预治疗, 闪回和自毁/鲁莽行为是两个重要的目标。

结论: 注意力不集中和睡眠障碍, 消极信念和消极的创伤相关情绪, 易怒/愤怒和自毁/鲁莽行为在普通人群和符合 PTSD 诊断标准的人群中均存在强相关。自毁/鲁莽行为在总样本和 PTSD 亚组分析中均是最核心的症状, 在未来的预防和干预治疗中应受到重点关注。

1. Introduction

Coronavirus disease 2019 (COVID-19) was defined a pandemic by the World Health Organization on 11 March 2020 and is one of the greatest public health challenges of the 21st century. Its impact on societies worldwide is multidimensional (Wang & Tang, 2020), ranging from widespread economic consequences (Pan & Yue, 2021) to substantial psychological problems such as post-traumatic stress disorder (PTSD), depression, anxiety, etc. (Haderlein, Wong, Yuan, Llorente, & Washington, 2020; Liang et al., 2020; Rutherford et al., 2021). The disease was defined as a collective trauma by some researchers (Horesh & Brown, 2020; Tang et al., 2020; Venkateswaran & Hauser, 2020), with an impact persisting in the community beyond that of the individuals experiencing symptoms. The increased presence of PTSD-related symptoms during the COVID-19 outbreak has been established both in survivors of COVID-19 as well as in health-care workers (see Salehi et al. (2021) for a recent meta-analysis). However, much remains to be learned about how individual PTSD symptoms relate to each other. Insight into which symptoms play a key role during the COVID-19 pandemic may facilitate targeted intervention for individuals with PTSD due to COVID-19. Therefore, it is crucial to investigate the structure of PTSD symptoms among populations exposed to the COVID-19.

PTSD consisted of a series of symptoms, including avoidance, intrusion, excessive arousal, emotional numbing, etc. (Deja et al., 2006). Previous studies have often used reflective models that assume the existence of a latent PTSD variable that explains individual differences in the observed PTSD item scores (Fried, 2015; Schmittmann et al., 2013). As a result, these analyses are typically focused on a total PTSD score, thereby ignoring causal interactions between individual symptoms. Indeed, a reflective latent variable model assumes that individual symptoms do not causally influence each other when conditioning on the presence of PTSD (Hofmann, Curtiss, & McNally, 2016). Recent advanced in psychometrics have brought forwards a different

approach to modelling psychopathology, called network analysis. According to network theory, psychological constructs can better be seen as networks of symptoms that causally influence each other (Borsboom, 2017). Network analysis can discover connections among symptoms in the same network and identify each symptom's centrality. Thus, it could be an ideal method to explore the construct of psychological problems (Klein, Harris, Björgvinsson, & Kertz, 2020; Levinson et al., 2017; Montazeri, de Bildt, Dekker, & Anderson, 2020).

Indeed, some have argued that PTSD can best be conceptualized as a system of causally interacting symptoms (McNally, 2012; McNally et al., 2015). In addition, earlier studies have indicated that the PTSD construct can better be seen as a continuum rather than a discrete category (Ruscio, Rusciob, & Keane, 2002). Studying the connections among PTSD symptoms could help us understand which specific symptoms contribute to individual differences on this PTSD continuum. This further highlights the importance of using network analysis to investigate both the PTSD symptom centrality and network connectivity (Epskamp & Fried, 2016; Fried, 2015).

Some earlier studies have applied network analysis to PTSD symptoms and found strong connections between hypervigilance and exaggerated startle response and between flashbacks and nightmares (Armour, Fried, Deserno, Tsai, & Pietrzak, 2017; Birkeland & Heir, 2017; Bryant et al., 2017; Cao et al., 2019; Spiller et al., 2017). However, these studies did not result in definitive conclusions regarding which symptoms were most central in the network. The identified connections varied across studies due to differential exposures (Asmundson, Stapleton, & Taylor, 2004). Recently, a cross-sectional study indicated that the network of PTSD symptoms related to COVID-19 differed from the structure observed during previous studies in the general population (Jiang, Ren, Yu, Tan, & Shi, 2020). Specifically, this study revealed that avoidance of thoughts and avoidance of reminders had a strong connection and the most central symptom was self-destructive/reckless behaviour in a PTSD network related to COVID-19. However, this study was limited by its relatively small sample (N = 338), possibly resulting in falsely suggesting the absence of the smaller symptom connections in the network. Their sample also primarily involved women. Furthermore, their network of PTSD symptoms was estimated in a sample of healthy individuals, making it unclear whether this structure generalizes to those suffering from PTSD.

Notably, though psychological research often involves specific hypotheses that are stated in the introduction section of the study, the current network analysis method was not used to test hypotheses, but rather an exploratory study to explore the PTSD symptom network structure

after COVID-19 exposure, both in the general population and a PTSD subgroup. Thus, we did not provide a concise hypothesis and our study aimed to use network analysis to discover the potential structure of COVID-19 related PTSD symptoms. In our study, we were both interested in the edge weights as well as the centrality index node strength. The edge weights showed the exact connections among symptoms, which could help us figure out which two symptoms had strong connections after adjusting for other symptoms in the network. And the centrality could help us discover which symptom was the most central, which means a symptom was most strongly connected with other symptoms in the network. By relating these two types of findings to other studies, we can evaluate whether our results are consistent with current theories in the PTSD field. For similar analysis methods please see some references in our study, i.e. works done by Armour et al. (2017) and Wang and Tang (2020), etc. We investigated the PTSD symptom network structure in 2858 individuals exposed to the COVID-19 outbreak and presented our results in detail in the Results section and discussed them in the Discussion section instead. Moreover, our analysis compares the structure found in the general population to the structure found in a PTSD subgroup (determined using the PCL-5 and DSM-5 criteria). This allows us to investigate whether the network connectivity and symptom centrality generalizes to that from the general population to the PTSD patient population. Studying differences in these dynamics may benefit future prevention, intervention, or treatment of PTSD related to COVID-19.

2. Methods

2.1. Sample

2.1.1. Participants

Participants were recruited from an online study 'the psychological status of Chinese adults during the COVID-19', which was conducted from February 1st to 10th, 2020. At the time of collecting data (1 February 2020), China reported 11,791 confirmed cases of COVID-19, 260 deaths due to COVID-19 and 247 recovered cases of COVID-19. At that time, lockdowns and stay-at-home requirements were in place in China. Therefore, the sample was collected using a web-based platform (https://www.wjx.cn/app/survey.aspx). Convenience sampling and snowball sampling were used to recruit participants. Initially, several key contact participants in specific groups such as a chief nurse, class tutor, or company manager, were recruited. Then, these contact participants were requested to distribute the questionnaire to their contacts through WeChat (a widely used communication tool in China). All participants completed an online questionnaire that assessed various socio-demographic, psychiatric, COVID-19 related, and health-

focused variables. The surveying platform collected only participants who could answer all the questions in this questionnaire. Therefore, there is no missing data in our study. Participants met our inclusion criteria if they were aged 18 years or older and provided online informed consent. Exclusion criteria were any conditions that affected the quality of the questionnaire response, for example, less than 10 minutes of response time, confusion of logic, etc. In total, 2858 valid samples were collected, and 558 participants met the diagnostic criteria of DSM-5. The characteristics of participants were shown in Table 1. According to previous studies (Armour et al., 2016; Jiang et al., 2020), covariates such as depression, anxiety, suicide ideation, social support, sex, and quality of life had no significant impact on the network of PTSD symptoms. Therefore, we did not consider them during the analysis stage. Of note, there was no question associated with skip-structures, which was mentioned as a requirement by Burger et al. (2020) in their developed reporting standards of network analysis. Nevertheless, we reported our results according to these standards.

2.1.2. Assessments

2.1.2.1. PTSD symptoms.
The post-traumatic Stress Disorder Checklist for DSM-5 (PCL-5; Weathers, Blake, & Schnurr et al., 2013) was used to assess the COVID-19-related PTSD symptoms in the past month. The PCL-5 is made of 20 items (total scores range: 0–80), all of which were assessed with a 5-point Likert scale: 0 = Not at all; 1 = A little bit; 2 = Moderately; 3 = Quite a bit; and 4 = Extremely. Cronbach's alpha of PCL-5 items in the current sample was 0.97. The diagnostic criteria of PTSD refer to the most recent edition of the DSM (DSM-5; American Psychiatric Association, A. P., & American Psychiatric Association, 2013), which characterizes PTSD as 20 individual symptoms in four groups: Intrusions (IN; B1-B5; as shown in Figure 1 in the Results section), Avoidance (AV; C1-C2), Negative

alterations in cognitions and mood (NACM; D1-D7), and Alterations in arousal and reactivity (AAR; E1-E6). Based on this, a diagnosis of PTSD currently requires that trauma survivors endorse a minimum of six symptoms (at least 1 IN, 1 AV, 2 NACM, and 2 AAR), except reporting significant functional impairment and the persistence of symptoms for more than one month (American Psychiatric Association, A. P., & American Psychiatric Association, 2013). Therefore, this study identified two target groups, i.e. the general population and the PTSD subgroup (as shown in Table 1) by these criteria. Of note, there was one question in our questionnaire, 'during the past year, did you experience severe trauma like a car accident, nature disaster, death of a family member?' Based on this question, we conducted analysis to assess whether the previous exposure would have impacted on the PTSD symptoms and the results showed no significant influence (see in Supplementary for details). Also, before participants responded to these questions, we indicated in our instruction that they should 'assess the impact of COVID-19 event on your life during the past month', thus the criterium A of PTSD was the COVID-19 event in this study.

2.1.2.2. Exposure to COVID-19.
A set of questions was used to assess the COVID-19 exposure: 1) were you infected with COVID-19, 2) have you had close contact with the infected person, 3) were your family members infected with the COVID-19, 4) did one or more of your family members have close contact with the infected person, 5) were your relatives or friends infected with COVID-19, 6) did your relatives or friends had close contact with the infected person of COVID-19, 7) did your neighbours infected, 8) Is there an infected person in your community. All eight questions contain two response options: 'Yes' and 'No.' We regarded the option 'Yes' as the exposure to COVID-19 and summed all items up to assess the level of traumatic exposure (range = 0–8). In our network analysis, we used the total scores of all items as a measure of COVID-19 exposure.
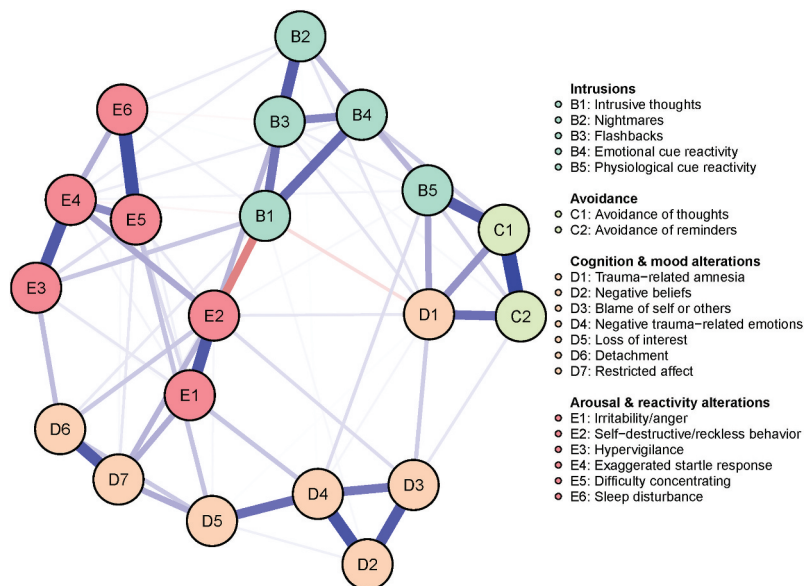
2.2. Data analysis

All data analysis was conducted by R (version 4.1.0). There were three main reasons why we used the network analysis method: first, it could take all the symptoms into one estimation procedure and discover the connections between PTSD symptoms; second, it could indicate which symptom was the most central, which could also be regarded as the key symptom and should be paid more attention; in the end, it could visualize the analysis result, which might be easier to

Table 1. Characteristics of participants (*N* = 2858).

	General group, *N* = 2858	PTSD subgroup, *N* = 558
Age (N, %)		
18–25 years old	691, 24.2	124, 22.2
26–30 years old	645, 22.6	143, 25.6
31–40 years old	891, 31.2	193, 34.6
41–50 years old	400, 14.0	68, 12.2
51–60 years old	143, 5.0	18, 3.2
61–70 years old	41, 1.4	8, 1.4
>70 years old	47, 1.6	4, 0.7
Sex (N, %)		
Male	1326, 46.4	334, 59.9
Female	1532, 53.6	224, 40.1
Exposure to COVID-19*		
YES	837, 29.3	224, 33.2
NO	2021, 70.7	373, 66.8

*Exposure to COVID-19 was determined based on eight questions asking participants about exposure to COVID-19 (described below in detail). In Table 1, scores >0 were defined as 'YES' and other scores were defined as 'NO'.

Figure 1. Network A1, containing the 20 DSM-5 symptoms of PTSD in the general population sample (*N* = 2858). Blue lines represent positive associations, red lines negative ones, and the thickness and brightness of an edge indicate the association strength.

be understood. Due to this method, we could discover the potential connections among symptoms and compare these results with the previous study (network study or another study), which might help us better know the associations among symptoms and we might use these results to develop new ways of prevention or treatment (i.e. we could target key symptoms for treatment, in this way the treatment might be more effective). However, we admit the implications of our findings to clinical practice could be limited because our network analyses are based on a sample with specific characteristics (i.e. COVID-19 exposures, nationality, age, gender, etc.). Despite this, future systematic reviews or meta-analyses could be used to compare our results with those of other studies performed on different samples to identify patterns that apply broadly across different contexts and to evaluate how exactly our study contributes to the PTSD field.

2.2.1. Network estimation

We estimated the structure of networks via two stages with the *R*-package qgraph (Epskamp & Fried, 2016). In the first phase, all analyses were conducted on the general population sample. First, we included all 20 PTSD symptoms in the estimation procedure (A1, Figure 1). Then, we added the exposure to COVID-19 total score as an additional node in the network (A2, Figure 2). These two figures visualize the multivariate dependencies of the data. In this process, a Gaussian Graphical Model was used to estimate the 190 pairwise association parameters in A1 and 210 pairwise association parameters in A2. These connections or edges between nodes range from −1 to 1 and can be interpreted as partial correlation coefficients, indicating the relationship between nodes A and B after controlling for the influence of all other

nodes in the network. We used the least absolute shrinkage and selection operator (LASSO) (Tibshirani, 1996) that sets very small edges to zero, thus minimizing false-positive connections. Besides, the networks were estimated based on polychoric correlations because PTSD symptoms and exposure to COVID-19 were measured on an ordered-categorical scale. Last of all, we removed the covariate COVID-19 exposure from the adjacency matrix of the 21-node network (A2), which results in the connections among the 20 PTSD symptoms controlling for the exposure to the COVID-19 (A2*). A2* consisted of the matrix of the 20-node network. Then, we subtracted this modified adjacency matrix A2* from the adjacency matrix of A1 (the 20 PTSD symptoms, not controlling for the covariate COVID-19 exposure) to derive a delta network (A3, see in the Supplementary Materials), which could be compared to 'A1 minus A2*'. At last, this delta network, A3, contains the change of A1 upon including covariate; thus, we could examine the impact of the covariates on the associations between 20 PTSD symptoms. Of note, the exact numbers of these edges in A3 were meaningless to some degree. The aim of this analysis was to visualize the differences between networks, a method also used by other researchers (McNally et al., 2015).

In the second network analysis phase, we repeated the procedure above on the PTSD sample. We got another three networks here: P1 (the 20 PTSD symptoms, Figure 3), P2 (the 20 PTSD symptoms and exposure to the COVID-19, Figure 4), and P3 (delta network, see in the Supplementary materials). At the end of the second phase, we examined the correlation between the A1 and P1 networks (correlation coefficient: 0.64) to test if the PTSD symptoms network among the general population and the PTSD subgroup
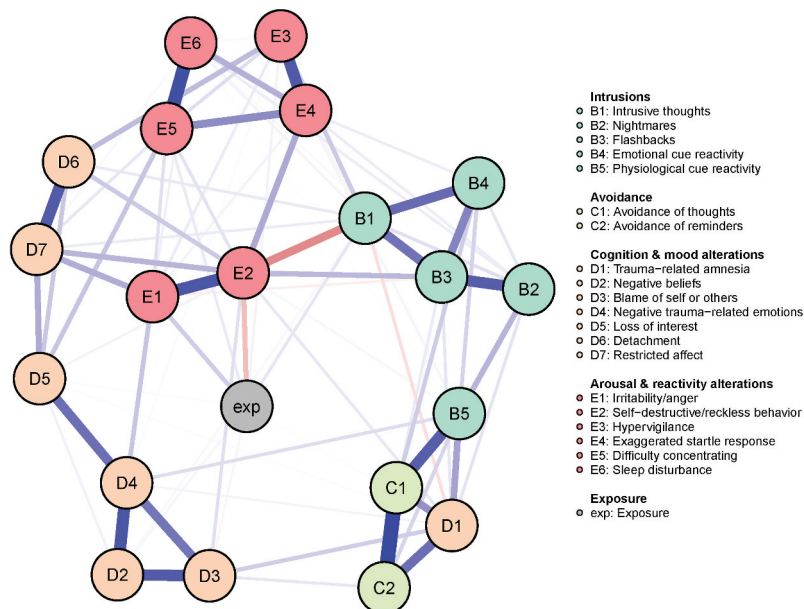
Figure 2. Network A2, containing the 20 DSM-5 symptoms of PTSD and the exposure to COVID-19 in the general population sample (*N* = 2858). Blue lines represent positive associations, red lines negative ones, and the thickness and brightness of an edge indicate the association strength.
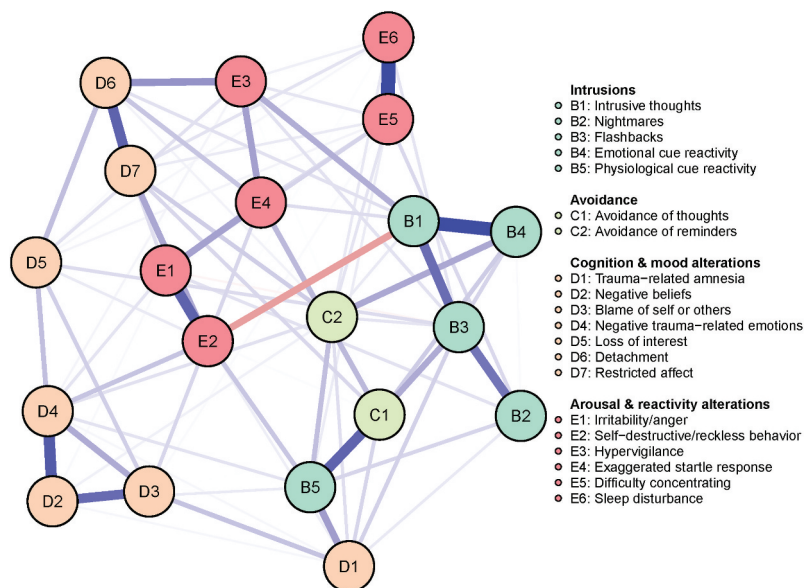
Figure 3. Network containing the 20 DSM-5 symptoms of PTSD in the PTSD subgroup (*N* = 558). Blue lines represent positive associations, red lines negative ones, and the thickness and brightness of an edge indicate the association strength.

were differential and correspondingly formed the delta network AP1 (see the Supplementary materials).

2.2.2. Centrality estimation

Centrality estimation was used to investigate the strength of each node, indicating which symptoms were most informative for PTSD. Often, there were three graph-theoretical centrality measures (Opsahl, Agneessens, & Skvoretz, 2010): node strength, closeness centrality, and betweenness centrality. Node strength calculates all edges of one symptom with all other symptoms, estimating the

strength of a node connected with the network directly. Closeness centrality sums the inverse of all shortest path lengths of one node with all other nodes, indicating how strongly a node is connected with the network indirectly. And betweenness centrality represents the frequency of one node lying on the shortest paths of any other two symptoms, indicating the ability of one node of connecting all other nodes in the network.

Of note, recent studies indicated that the betweenness centrality and closeness centrality estimates tend to be unstable (Bringmann et al., 2019; Hallquist, Wright,
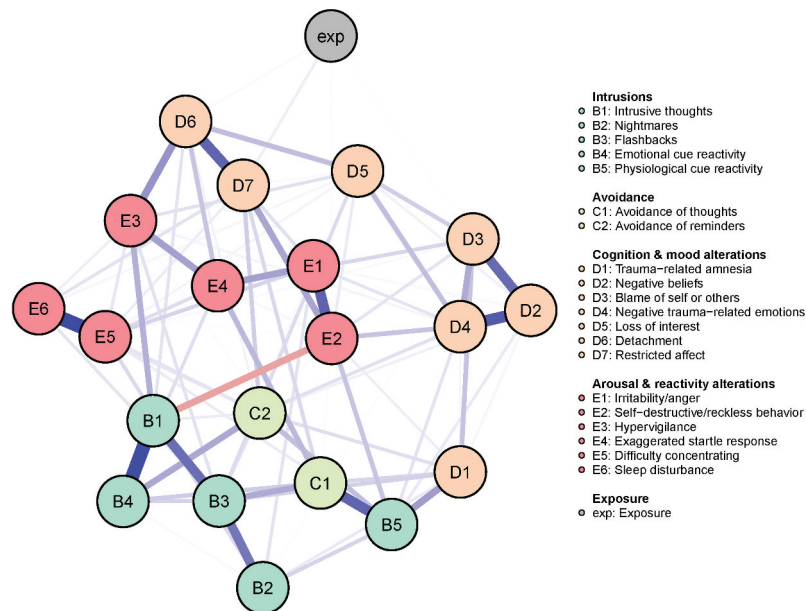
Figure 4. Network containing the 20 DSM-5 symptoms of PTSD and the exposure to COVID-19 in the PTSD subgroup (*N* = 558). Blue lines represent positive associations, red lines negative ones, and the thickness and brightness of an edge indicate the association strength.

& Molenaar, 2021). Therefore, we focused on the node strength and its accuracy and stability in this study.

2.2.3. Accuracy and stability estimation

To cope with the unclear stability and accuracy in edge weight estimates (Epskamp & Fried, 2016), we bootstrapped (1000 iterations) the edge weights (Epskamp & Fried, 2018), further allowing a test for significant differences between edge weights based on between the bootstrapped 95% confidence intervals. Also, we took the correlation stability (CS)-coefficient to assess the strength centrality index (Costenbader & Valente, 2003). A CS-coefficient should be at least 0.25 for the centrality to be stable, preferably above 0.5 (Epskamp, Borsboom, & Fried, 2018).

2.2.4. Visualization

Positive edges were printed in blue, whereas negative ones were in red. Besides, the stronger a connection was, the thicker and more saturated it would be. We used the Fruchterman-Reingold algorithm (Fruchterman & Reingold, 1991) that places nodes with stronger (and/or more) connections more closely together. We set the maximum edge value across all networks to 0.45 (Armour et al., 2016), the strongest edge identified across networks. Thus, the saturation and thickness of edges could be compared directly throughout networks. Also, we used a minimum edge weight of 0.03 in all networks to enhance the interpretability of the graphs.

2.2.5. Network comparison test

To compare the networks between the general population and the PTSD subgroup population, we conducted the network comparison test to compare the networks on four aspects: network invariance, global strength invariance, edge invariance and centrality invariance (Borkulo et al., 2017). The network invariance and the global strength invariance were used to assess the differences between the whole network structure, while the edge invariance was applied to test the differences of edges and the centrality invariance was used to discover the invariance of the strength centrality between networks. All analysis was conducted by *R*-package 'Networkcomparisontest' and details about this method could be found in Borkulo et al.'s work (2017).

Of note, all analytic codes of our study were available in Supplementary named 'analytic codes'.

3. Results

3.1. Sample characteristics

Participants ranged in age at the time of assessment from 18 to > 70 years old and the females accounted for 53.6% of the sample. The average PCL-5 score was 17.15 (SD = 17.64), and a total of 558 participants (19.52%) had reached the criteria of PTSD according to PLC-5 and DSM-5. Among individuals reporting PTSD, the average PCL-5 score was 46.74 (SD = 12.57). 29.3% (*N* = 837) of the general population had been exposed to the COVID-19, whereas 33.2% (*N* = 224) of the individuals with PTSD had an exposure history. Table 2 demonstrated the details about each of the PTSD symptoms.

3.2. Networks

Figure 1 visualizes the structure of COVID-19-related PTSD symptoms (A1) in the general population. Apart from the associations between intrusive

Table 2. Means and standard deviations of scores on the 20 PCL-5 questions measuring post-traumatic stress disorder (PTSD) symptom, and the scores representing exposure to COVID-19.

	Overall group, N = 2858		PTSD group, N = 558		General group, N = 2300	
	Mean	SD	Mean	SD	Mean	SD
Intrusions						
B1: Intrusive thoughts	2.06	1.14	2.67	0.91	1.91	1.14
B2: Nightmares	0.69	1.04	2.08	1.02	0.35	0.71
B3: Flashbacks	0.95	1.18	2.40	0.93	0.60	0.94
B4: Emotional cue reactivity	1.24	1.17	2.53	0.89	0.92	0.99
B5: Physiological cue reactivity	0.67	1.04	2.25	0.91	0.28	0.62
Avoidance						
C1: Avoidance of thoughts	0.74	1.05	2.35	0.84	0.35	0.65
C2: Avoidance of reminders	0.77	1.08	2.41	0.78	0.38	0.70
Cognition and mood alterations						
D1: Trauma-related amnesia	0.64	1.03	2.29	0.89	0.25	0.57
D2: Negative belief	0.76	1.07	2.28	0.89	0.38	0.73
D3: Blame of self or others	0.70	1.05	2.25	0.88	0.33	0.67
D4: Negative trauma-related emotions	0.66	1.05	2.26	0.91	0.27	0.63
D5: Loss of interest	0.74	1.07	2.30	0.86	0.36	0.72
D6: Detachment	1.02	1.13	2.42	0.45	0.69	0.92
D7: Restricted affect	0.85	1.10	2.38	0.83	0.48	0.81
Arousal and reactivity alterations						
E1: Irritability	0.74	1.07	2.30	0.87	0.37	0.71
E2: Self-destructive/reckless behaviour	0.55	1.00	2.14	0.96	0.16	0.51
E3: Hypervigilance	0.98	1.12	2.44	0.84	0.62	0.86
E4: Exaggerated startle response	0.71	1.05	2.30	0.85	0.33	0.66
E5: Difficulty concentrating	0.81	1.08	2.34	0.83	0.44	0.75
E6: Sleep disturbance	0.86	1.12	2.35	0.90	0.50	0.83
Covariate						
Exposure to the COVID-19	0.60	1.20	0.81	1.60	0.55	1.08

thoughts (B1) and self-destructive/reckless emotions (E2) and that between intrusive thoughts (B1) and trauma-related amnesia (D1), both of which were negative, all other edges were positive. Some symptoms belonging to the same symptom group showed a strong connection: the avoidance of the thoughts (C1) and the avoidance of the reminders (C2), the difficulty concentrating (E5), and the sleep disturbance (E6), for example. Also, the avoidance of the thoughts (C1) and physiological cue reactivity (B5) showed considerable connection though they did not belong to the same clinical group. The five strongest edges in the network emerged between avoidance of thoughts (C1) and avoidance of reminders (C2); difficulty concentrating (E5) and sleep disturbance (E6); negative beliefs (D2) and negative trauma-related emotions (D4); irritability/anger (E1) and self-destructive/reckless behaviour (E2); hypervigilance (E3) and exaggerated startle response (E4). Figure 2 showed the PTSD symptom network structure in the general population sample after adding exposure to COVID-19 to the network (A2). Though the exposure showed a positive connection with some symptoms, such as irritability/anger (E1) and a negative connection with self-destructive/reckless emotions (E2), the

coefficient between network A1 and A2* was 0.9986, indicating high correlation. In addition, the sum of edges in this network reduced from 10.83 to 10.76 after controlling for exposure. Besides, the delta network A3 (available in the Supplementary materials) was nearly empty and featured few very weak edges, with the strongest edge weight being only 0.013. In conclusion, the estimated PTSD symptoms network structure is largely unaffected by whether COVID-19 exposure is included in the network, indicating the connections might be robust and convincible in the general population sample.

Similar to the results of the general population sample, Figure 3 represents the PTSD symptom network structure in the PTSD group (P1) and Figure 4 showed the network structure after adding exposure to COVID-19 to the network (P2). Though some connections were of equal sign and strength as those in network A1 (e.g. the difficulty concentrating (E5) and the sleep disturbance (E6)), some connections changed their strength (e.g. the avoidance of the thoughts (C1) and the avoidance of the reminders (C2)), or even became totally different (e.g. the strength between intrusive thoughts (B1) and trauma-related amnesia (D1) is 0 in P1). Although exposure to COVID-19 showed different connections with the symptoms from A1 as shown in P2, the correlation between networks P1 and P2* is 0.9981, and the sum of edges of 20 symptoms was reduced from 10.01 to 9.96 once controlling for exposure, indicating the exposure 'explained away' only about 0.50% of the connectivity of the PTSD symptoms. In sum, the estimated PTSD symptoms network structure is largely unaffected by whether exposure to COVID-19 is included in the network, indicating the connections might be robust and convincible in the PTSD subgroup sample.

Furthermore, considering the network is robust and COVID-19 exposure had little influence on the network, we examined the correlation between network A1 and P1 to investigate the differences between the general population and the PTSD population. The correlation was 0.6356 and the delta network's (AP1) sum of edges of 20 symptoms was 7.11, with an average edge weight of 0.037 and a maximum edge weight of 0.38 (the connection between the avoidance of the thoughts (C1) and the avoidance of the reminders (C2)). These results indicated that there were considerable differences between the network in the general group and the PTSD group.

3.3. Centrality

Figure 5 presents the standardized estimates of centrality in the general population sample. In light of the negligible influence of COVID-19 exposure on the
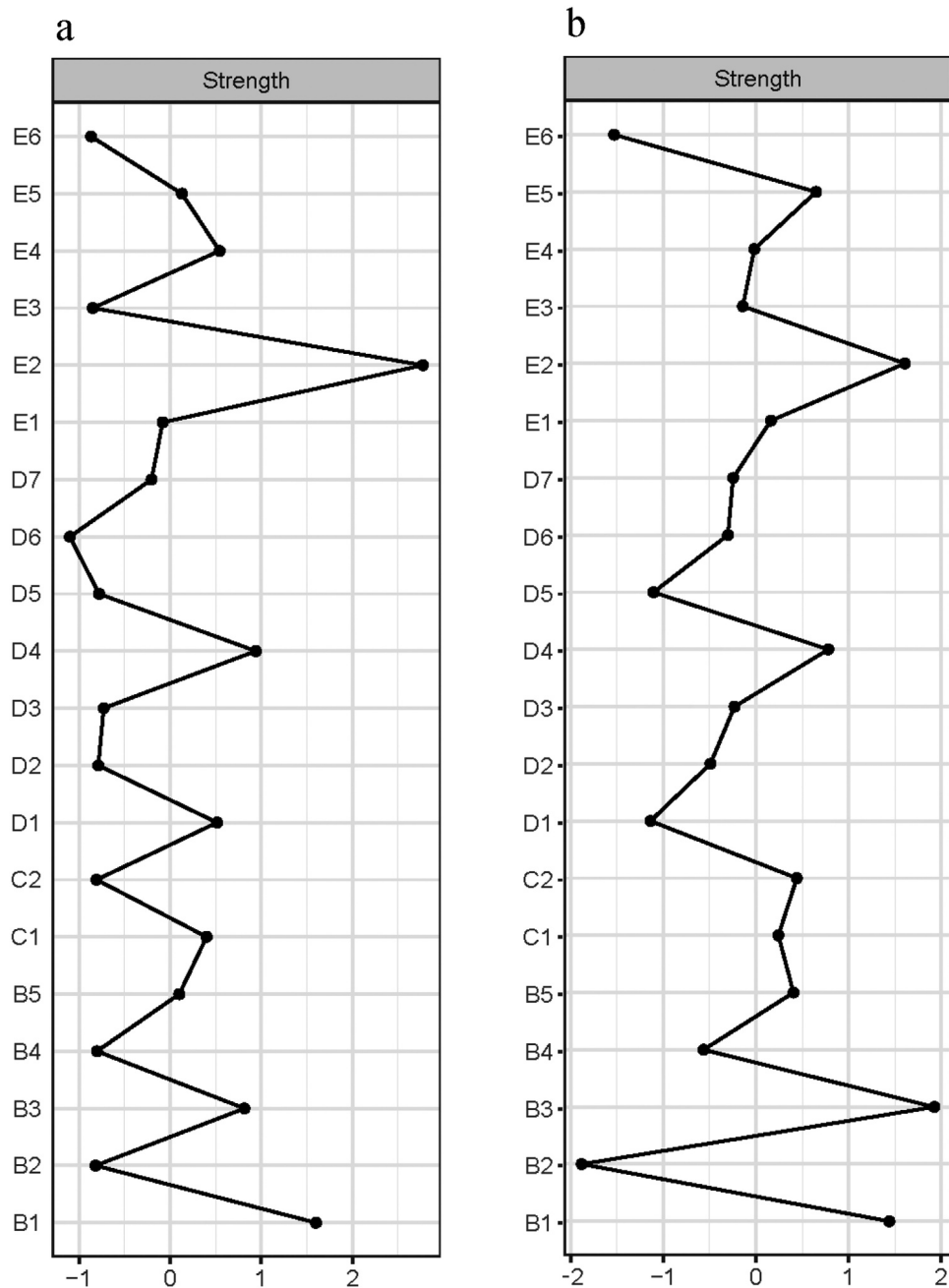
Figure 5. (a) Node strength centrality estimates for the 20 DSM-5 PTSD criterion symptoms in the full sample (*N* = 2858). The question codes are defined as in Figure 1. (b) Node strength centrality estimates for the 20 DSM-5 PTSD criterion symptoms in the PTSD group (*N* = 558). The question codes are defined as in Figure 3.

PTSD symptom network (see above *Networks*), we used network A1 to investigate the centrality. The centrality estimates were substantially interrelated: correlation of 0.70 between closeness and betweenness, correlation of 0.56 between closeness and node strength and correlation of 0.77 between node strength and betweenness. Because of these high intercorrelations and as mentioned above that closeness and betweenness estimates tend to be more unstable (Bringmann et al., 2019; Hallquist et al., 2021), we focused our interpretation of the most relevant symptoms on node strength centrality on behalf of this study. As shown in Figure 5, the five nodes with the

highest node strength were self-destructive/reckless behaviour (E2), intrusive thoughts (B1), flashbacks (B3), negative trauma-related emotions (D4) and exaggerated startle response (E4), while, the least central node, which had the few and weak connections with other nodes, was detachment (D6). All these results fitted the network in Figure 1.

Similarly, Figure 5(b) presents the standardized node strength centrality estimates in the PTSD subgroup. In this group, centrality estimates were also substantially interrelated: correlation of 0.72 between closeness and betweenness, correlation of 0.61 between closeness and node strength, correlation of 0.78 between node

strength and betweenness. As Figure 5(b) showed, the five nodes with the highest node strength were flashbacks (B3), self-destructive/reckless behaviour (E2), intrusive thoughts (B1), negative trauma-related emotions (D4), and difficulty concentrating (E5), while, the least two central nodes, which had the few and weak connections with other nodes, were nightmares (B2) and sleep disturbance (E6). All these results fitted the network in Figure 3.

3.4. Network accuracy and stability

The accuracy and stability of the 20 PTSD symptoms network (A1) in the general group were examined and the results are presented in Figure 6. Figure 6(a) shows the bootstrapped edge weights, which revealed that 95% confidence intervals for the edge weights were mostly overlapping, indicating considerable accuracy was estimated in the network. And Figure 6(b) represented the
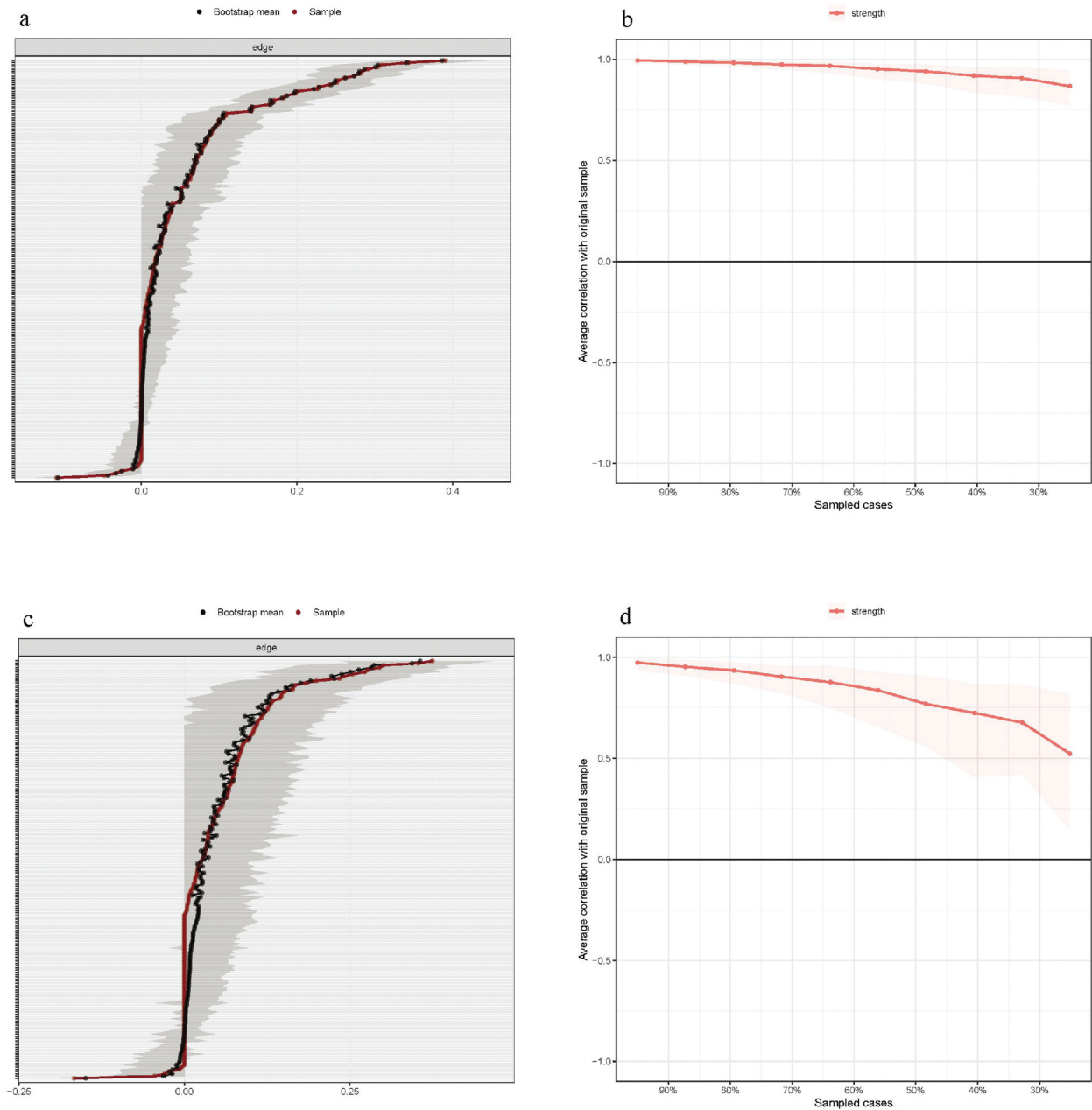
Figure 6. (a) Robustness of network of 20-items PTSD symptoms in the general population sample. The red line indicates the edge weight values and the grey lines represent the bootstrapped 95% confidence intervals (CIs). (b) Subsetting bootstrap for the 20-item PTSD network in the overall group that shows the average correlations between centrality indices of the original network constructed on the full participants sample compared to networks estimated on samples with fewer participants. (c) Robustness of network of 20-items PTSD symptoms in the PTSD subgroup. The red line indicates the edge weight values and the grey lines the 95% CIs. (d) Subsetting bootstrap for the 20-item PTSD network in the PTSD group that shows the average correlations between the node strength centrality index of the original network constructed on the full PTSD sample compared to networks estimated on samples with fewer participants.

subset bootstrap and the CS-coefficient was 0.75 for node strength. As mentioned in the Methods section, the coefficient could not be below 0.25 and preferably above 0.5. Therefore, this network showed great stability. To get details about accuracy and stability analyses for this network, readers could view the Supplementary material, including edge weights significance tests (testing for significant differences for all edges) and centrality difference tests (testing for centrality differences for all nodes). Similarly, the accuracy and stability of the 20 PTSD symptoms network (P1) in the PTSD group were examined and results were presented in Figures 6(c and d). Figure 6(c) showed that the P1 had a considerable accuracy and Figure 6(d) indicated the P1, with a CS-coefficient of 0.36 which was beyond the 0.25, had considerable stability as well.

3.5. Network comparison

Visual inspection of networks A1 and P1 revealed that the network estimated in the general population might be denser than the PTSD subgroup – for the density of network of general population was 0.61 and was 0.53 of PTSD subgroup. Also, the negative connection between intrusive thoughts (B1) and trauma-related amnesia (D1) was absent in the PTSD subgroup network. The global node strength of the general group was 9.53, which was a bit higher than 9.40 of the PTSD subgroup. However, these differences could also be due to the larger sample of the general group as the power to detect an edge is higher in the general population sample than in the PTSD subgroup. Nevertheless, the results still indicated that the difference between those networks was statistically significant ($S = 0.13$, $p = .006$).

Besides, the omnibus test on invariance of network structure was conducted to investigate the differences in edges. Results indicated significant differences between the edges of the two networks ($M = 0.29$, $p = .001$). Therefore, we performed post hoc testing of all edges to investigate which edges(s) varied in networks. It had to be noted that we tested them all without applying a correction for multiple comparisons for our analyses were exploratory and had no a priori hypotheses. Results showed that 14 edges differed significantly between the two networks (See details in Supplementary). Furthermore, we investigated the invariance of strength centrality and it turned out that three nodes differed significantly between the two networks: Flashbacks (B3), Trauma-related amnesia (D1) and Detachment (D6).

4. Discussion

In this study, we applied a network analysis to the DSM-5 PTSD symptom scores of 2858 Chinese individuals exposed to the COVID-19 pandemic. We compared the networks between the general population and a PTSD subgroup (those who matched the criteria for PTSD according to DSM-5 and PCL-5). Our results showed a negligible influence of COVID-19 exposure on the PTSD symptom structure, both in the general population and in the PTSD subgroup. Note that this does not mean that COVID-19 exposure has no impact on PTSD because our results merely suggest that COVID-19 exposure did not change the relationship among the PTSD symptoms in the network.

4.1. PTSD network in the general population

In the current study, PTSD symptoms were generally positively connected to each other. The five strongest edges in the network emerged between avoidance of thoughts (C1) and avoidance of reminders (C2); difficulty concentrating (E5) and sleep disturbance (E6); negative beliefs (D2) and negative trauma-related emotions (D4); irritability/anger (E1) and self-destructive /reckless behaviour (E2); hypervigilance (E3) and exaggerated startle response (E4). And the negative connections were between intrusive thoughts (B1) and trauma-related amnesia (D1); intrusive thoughts (B1) and self-destructive/reckless behaviour (E2).

For these connections, the strong connection between hypervigilance (E3) and exaggerated startle response (E4) was consistent with previous studies (Armour et al., 2017; Birkeland & Heir, 2017; Bryant et al., 2017; Jiang et al., 2020; McNally, 2016; McNally et al., 2015; Spiller et al., 2017). Earlier research suggested a feedback loop between hypervigilance and exaggerated startle response (McNally et al., 2015), which is supported by a Sensitization Model of PTSD, indicating that survivors may become sensitive to the threat and show an exaggerated startle response after exposure to traumatic occurrences (Stam, 2007). In addition, the connection between difficulty concentrating (E5) and sleep disturbance (E6) may be explained by sleep disturbance arousing a series of adverse outcomes, including lack of concentrating (Harvey, 2009; Pagel, Forister, & Kwiatkowki, 2007). Earlier research (Nixon & Kling, 2009) indicated that trauma-related emotions might act as a buffer to negative emotions, and may indirectly lead to a restructuring of negative beliefs, which could explain the connection between negative beliefs (D2) and negative trauma-related emotions (D4). The connection between irritability/anger (E1) and self-destructive/reckless behaviour (E2), may be explained by reckless behaviour being a way to release anger. Furthermore, anger is associated with self-control (Jensen-Campbell, Knack, Waldrip, & Campbell, 2007), suggesting that the lower self-control of angry individuals may also result in reckless behaviour. It is important to note that these connections matched the classification of the Hybrid Model of PTSD (Armour et al., 2015), suggesting that our study's findings are consistent with Armour et al.'s work.

However, in contrast to previous studies, there were several negative connections between PTSD symptoms in our general population network. The negative connection between intrusive thoughts (B1) and trauma-related amnesia (D1) might be explained that PTSD could result in a deficit in the inhibitory processes in the memory (Cottencin et al., 2006). Cottencin and colleagues conducted a directed forgetting study, indicating that PTSD patients could have a deficit in the inhibitory processes in the memory which could both reduce amnesia and contribute to the intrusive thoughts to some degree. Birkeland and Heir (2017) indicated that intrusive thoughts (B1) could bring patients to the trauma memory repeatedly, which could reduce the severity of the trauma-related amnesia (D1). In addition, Salkovskis and Campbell (1994) claimed that thought suppression might induce the occurrence of intrusive thoughts and as mentioned above, the reckless behaviour might release the emotions (Jensen-Campbell et al., 2007) and reduce these negative thoughts, which could explain the negative connection between intrusive thoughts (B1) and self-destructive/reckless behaviour (E2).

Assessing the robustness of symptom centrality revealed that the most central symptoms did not differ substantially from each other in their centrality and should be considered roughly equally important. The most central symptoms were self-destructive/reckless behaviour (E2), intrusive thoughts (B1), flashbacks (B3), negative trauma-related emotions (D4), and exaggerated startle response (E4), and we concluded that they could be of greatest clinical significance in the normal population who experienced COVID-19 outbreak. It is noteworthy that these symptoms were similar to Jiang et al.'s study (the self-destructive/reckless behaviour is of highest node strength; Jiang et al., 2020) but different from Armour et al.'s study (the most central symptoms were negative trauma-related emotions, flashbacks, detachment, and physiological cue reactivity; 2017), which might result from the different type of trauma (Armour & Shevlin, 2009). This may be because Jiang et al.'s study and our study were both aimed at COVID-19 whereas Armour et al.'s study focused on trauma resulting from war. Moreover, differences between studies in the time interval between the traumatic event and moment the study was conducted may have contributed to this discrepancy (Jiang et al., 2020) and some networks of depression symptoms could vary across different stressful life events as well (Cramer, Borsboom, Aggen, & Kendler, 2012; Fried, 2015). Notably, the interventions of the potential central symptoms might facilitate the relief of most PTSD symptoms.

4.2. PTSD network in the PTSD subgroup

In this study, PTSD symptoms were generally positively connected to each other. The five strongest edges in the network emerged between: difficulty concentrating (E5) and sleep disturbance (E6); intrusive thoughts (B1) and emotional cue reactivity (B4); negative beliefs (D2) and negative trauma-related emotions (D4); irritability/anger (E1) and self-destructive/reckless behaviour (E2); detachment (D6) and restricted affect (D7). And the negative connection was between intrusive thoughts (B1) and self-destructive/reckless behaviour (E2).

For these connections, the strong connections between difficulty concentrating (E5) and sleep disturbance (E6), negative beliefs (D2) and negative trauma-related emotions (D4), irritability/anger (E1) and self-destructive/reckless behaviour (E2), and intrusive thoughts (B1) and self-destructive/reckless behaviour (E2) could be explained as above. In addition, an explanation for the connection between detachment (D6) and restricted affect (D7) may be that the PTSD patients disengage not only from negative emotions related to trauma but also from positive emotions after trauma due to the detachment symptoms, which might limit the effects on mood (Litz, Orsillo, Orsillo, & Weathers, 2000; Shepherd & Wild, 2014). Besides, Armour et al. (2016) indicated that though the connection was only strong between nightmares and flashbacks, most re-experiencing symptoms were linked either directly or indirectly through other symptoms (e.g. nightmare was linked to emotional cue reactivity through flashbacks). Also, Jiang et al. (2020) discovered strong connections between intrusive thoughts and nightmares, and flashbacks and emotional cue reactivity. These results suggest a high correlation among intrusive symptoms, which might explain the connection between intrusive thoughts (B1) and emotional cue reactivity (B4) in our study. More importantly, such connections revealed a latent structure of PTSD symptoms related to COVID-19, which was consistent with the Hybrid Model of PTSD (Armour et al., 2015), indicating mutual evidence between our study and Armour et al.'s work.

As for as the centrality strength was concerned, the most central symptoms were flashbacks (B3), self-destructive/reckless behaviour (E2), intrusive thoughts (B1), negative trauma-related emotions (D4), and difficulty concentrating (E5). The differences among studies could result in different trauma or the different intervals between exposures and studies as mentioned above as well (Cramer et al., 2012; Fried, 2015; Jiang et al., 2020).

4.3. Differences between the general group and PTSD subgroup

Our network comparisons suggest that there were similarities and differences in the network structures of the general population and the PTSD subgroup. For example, equally strong connections were found in both groups for the symptom sets difficulty concentrating (E5) and sleep disturbance (E6), negative beliefs (D2) and negative trauma-related emotions (D4), and irritability/anger (E1), and self-destructive

/reckless behaviour (E2). However, the presence of negative connections differed between the two groups: In the general population intrusive thoughts (B1) and trauma-related amnesia (D1) were negatively connected, as were intrusive thoughts (B1) and self-destructive/reckless behaviour (E2). In the PTSD group, intrusive thoughts (B1) was negatively connected with self-destructive/reckless behaviour (E2).

In terms of centrality strength, the top four strongest central symptoms were the same in the two groups, whereas the order changed between groups: in the general population self-destructive/reckless behaviour (E2) was most strongly connected to other symptoms in the network, while in the PTSD group this was flashbacks (B3). Such differences may be due to differences between the two population in the position of individuals on the PTSD continuum (Ruscio et al., 2002). Therefore, our results indicate that on the one hand, the same connections between symptoms were considerably stable across groups, and on the other hand, these differences in strength indicated that symptoms might have different impacts on the general population and PTSD sub-population.

5. Limitations and implications

It has to be admitted that there were some limitations in our study: First, the robustness analysis showed a moderate uncertainty in the PTSD group regarding the estimation of the edge weights and centrality parameters. Therefore, future research could study the PTSD network structure in an even larger sample of PTSD patients to investigate whether our centrality and network connection estimates can be replicated. Second, the current study was cross-sectional, which inhibits conclusions regarding causal influences between symptoms. This makes it unclear whether a particular symptom truly causes the occurrence of another symptom in the network. Therefore, prospective studies are needed to solve this problem. Third, the data was collected through a web-based and self-report questionnaire, which could limit the validity and reliability of our findings (Fried & Cramer, 2017). However, the PCL-5 is a well-validated questionnaire and the reliability estimated in our current sample was excellent. Nevertheless, future research could replicate our network analysis based on PTSD symptom measurements in terms of specialized and structured interviews. Fourth, the CS-coefficient of PTSD subgroup was 0.36, suggesting suboptimal stability of the strength centrality index. Although this coefficient was larger than the minimum requirement of 0.25, any coefficient lower than 0.5 should be treated cautiously. Finally, the exposure was calculated with no weights in our study. During our analysis, we did not take the weights of the eight questions about exposure to COVID-19 into consideration, which might limit the extent to which this score represents the true exposure. Future studies could assign weights to the different exposures and take the

severity of COVID-19 in a participant's living situation into consideration as well.

Despite the limitations, our study has potential strengths and implications as well. One strength of our study is that we overcome the limitation of both Jiang et al. (2020) and Armour et al.'s (2017) work by focusing on the differences in network structure between the general and clinical population. A second strength is that the connections of symptoms in both populations are fully consistent with the Hybrid Model of PTSD (Armour et al., 2015), which could classify the clusters of PTSD better than DSM-5 (Armour, Müllerová, & Elhai, 2016), indicating that our findings are consistent with Armour et al.'s work and revealing the potential structure of PTSD related to COVID-19.

Our results shed light on the prevention and intervention of PTSD related to COVID-19 in the future. One implication of our work is that specific PTSD symptoms could be targeted when treating patients suffering from PTSD due to COVID-19. Our study found high positive connections between 1) avoidance of thoughts and avoidance of reminders, 2) difficulty concentrating and sleep disturbance, 3) negative beliefs and negative trauma-related emotions, 4) irritability/anger and self-destructive/reckless behaviour, 5) hypervigilance and exaggerated startle response in the general population. And negative connections were found in the general population between intrusive thoughts and trauma-related amnesia, and intrusive thoughts and self-destructive/reckless behaviour. Therefore, clinicians could target related symptoms in treatment planning at the same time and contribute especially to the treatment of some symptoms that might be difficult to intervene on, such as difficulty concentrating. More specifically, because of the high connection between difficulty concentrating and sleep disturbance, we could target sleep disturbance in treatment instead, and the alleviation of this symptom could break down other highly related symptoms like difficulty concentrating. In addition, the treatment of the most central symptom, self-destructive/reckless behaviour in this network, could result in alleviation of other related symptoms in this network, and particularly prevent the general population from developing PTSD disorder. The negative connections also showed great importance when concentrating on the intervention of one symptom like intrusive thoughts in the general population. Specifically, it is essential to pay attention to trauma-related amnesia and self-destructive/reckless behaviour, since they were negatively connected with intrusive thoughts and might get worse along with the treatment of intrusive thoughts. Secondly, similar to our discussion above, the five strongest edges in the network in the PTSD subgroup emerged between the symptom sets: 1) difficulty concentrating and sleep disturbance; 2) intrusive thoughts and emotional cue reactivity; 3) negative beliefs and negative trauma-related emotions; 4) irritability/anger and self-destructive/reckless behaviour; 5) detachment and restricted affect. In the PTSD group a negative connection

was found between intrusive thoughts and self-destructive /reckless behaviour. Taking those connections of symptoms into consideration can be important when intervening or treating PTSD related to COVID-19 in the clinical population. For instance, flashbacks and self-destructive/reckless behaviour could be targets for conducting an effective treatment. Moreover, the network generated from the general population suggests that the prevention of PTSD could be done by intervening or identifying the central symptoms in the early period. The network generated from the PTSD subgroup revealed more effective ways for treatment as well. Nevertheless, we emphasize that the cross-sectional nature of our study prevents conclusions regarding causal influences between symptoms. It remains unclear whether our centrality indices can be used as a measure of symptoms that can best be intervened upon. Future research could use longitudinal network analyses to identify whether the symptoms discussed above turn out to be causally efficacious.

6. Conclusion

This study explores the construct of PTSD symptoms under the COVID-19 pandemic in China and reveals its similarities and differences in symptom connectivity between the general Chinese population and individuals reporting PTSD. Results indicate similar positive connections between concentration difficulty and sleep disturbance, negative beliefs and negative trauma-related emotions, and irritability/anger and self-destructive/reckless behaviours in both the general and PTSD-reported populations. We therefore argue that self-destructive/reckless behaviours are a core symptom of COVID-19 related PTSD, which needs more attention in future psychiatric programmes.

Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy reasons. For data request, please contact the corresponding author by email: jing624218@163.com.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Ethics statement

The Ethics Committee of Peking University Medical Center approved this study. All participants were informed of the survey's purpose and their rights to decline their information. Also, electronic informed consent was obtained from these survey participants.

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