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Prospective network of post-traumatic stress disorder (PTSD) symptoms across adolescent survivors with distinct trajectories of PTSD: A cohort study of the Wenchuan earthquake

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ABSTRACT

There are multiple trajectories of post-traumatic stress disorder (PTSD) symptoms following disasters. Unraveling the patterns of interactions between PTSD symptoms across distinct PTSD trajectories is crucial. This study was aimed at investigating the temporal sequences, changes, and predictive symptoms in PTSD networks over time across distinct PTSD trajectory groups. Data were exacted from the Wenchuan Earthquake Adolescent Health Cohort (WEAHC) study. The current study included 1022 adolescents (424 males) who participated in follow-up surveys at 12 months and 24 months post-earthquake. Self-reported PTSD symptoms were assessed with the Post-traumatic Stress Disorder Self-Rating Scale. The between-person network revealed significant differences across distinct trajectories. In the chronic dysfunction group, “Intrusive thoughts” had the strongest value in predicting on other PTSD symptoms. In contrast, “Difficulty in study or work” in the recovery group and “Physiological cue reactivity” in the resistance group were highly associated with the remission of other PTSD symptoms. These findings underscore the importance of "Difficulty in study or work" and “Physiological cue reactivity” for promoting the spontaneous remission of PTSD and further suggest that “Intrusive thoughts” maybe helpful to minimize the subsequent presence of other PTSD symptoms. Future research should investigate the causality and associations between within-person networks.

1. Introduction

Post-traumatic stress disorder (PTSD) is among the most prevalent mental health outcomes of earthquake exposure, and has a prevalence rate ranging from 2.5% to 60.0% in children and adolescents, according to a meta-analysis by Tang et al. (2017). PTSD symptoms can cause a range of short-term and long-term negative consequences on adolescents, such as serious functional impairment, considerable disability, and detrimental effects on brain development (Hong & Efferth, 2016; Weiss et al., 2020). Moreover, PTSD symptoms can also lead to substantial burdens on the economy and society (Benfer et al., 2021). Hence, more research is needed to better understand the development and course of PTSD symptoms among earthquake survivors.

PTSD is characterized by a variable course, as described in the Diagnostic and Statistical Manual (DSM). This course can take the form of an acute or chronic condition, with symptoms remitting after only one to three months, or delaying resolution until six months, or even lasting for years (APA, 2013; Santiago et al., 2013). Indeed, existing studies (Bonanno & Mancini, 2012; Bonanno, 2005; Bonanno et al., 2008; Norris et al., 2009; Osofsky et al., 2015; pp. 0, 1242; Santiago et al., 2013) have demonstrated multiple trajectories of PTSD symptoms following disasters, highlighting the importance of obtaining more knowledge about distinct trajectories. Researchers have identified four prototypical patterns (Bonanno & Mancini, 2012; Bonanno et al., 2008;

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Bonanno et al., 2012; Fan et al., 2015; pp. 0, 1242; Norris et al., 2009; Osofsky et al., 2015; Santiago et al., 2013): chronic dysfunction (consistently moderate or severe and stable symptoms), delayed dysfunction (initially absent or minimal symptoms and postponed manifestation of severe symptoms), recovery (initially moderate or severe symptoms followed by a gradual decrease in symptoms), and resistance (absent or minimal symptoms over time). Moreover, many risk factors, including gender, ethnocultural minority status, adverse life events, social support, and coping style, have been found to significantly influence on the probability of trajectory classification of PTSD symptoms (Fan et al., 2015; Osenbach et al., 2014), However, the essential characteristics of PTSD have yet to be identified, possibly because PTSD symptoms create feedback loops that cause individuals to spiral down into a state of extended symptom activation (Borsboom, 2017). Together, prior work had highlighted the importance of understanding the patterns of interaction between their symptoms in adolescents with distinct PTSD trajectories after earthquake exposure (Osofsky et al., 2015; pp. 0, 1242; Santiago et al., 2013). However, few studies have examined the interplay between PTSD symptoms across distinct trajectories. Therefore, the conceptualization of PTSD symptoms as systems of interacting symptoms across distinct changing patterns after earthquakes is needed.

Network analysis has become a booming sector in the psychopathological field, which can reveal direct interactions among symptoms of psychiatric disorders and further depict them as a network graph (Borsboom, 2017; Borsboom & Cramer, 2013; Cramer et al., 2010). A network graph is typically composed of two building blocks: nodes are visualized as circles, representing individual symptoms, and edges are displayed as lines between nodes, indicating the relationships between symptoms (Borsboom & Cramer, 2013). The network approach is based on the assumption that psychiatric disorders are phenomena that emerge as a complex network of mutually reinforcing symptoms (Borsboom, 2017). Importantly, network analysis can identify the most influential symptoms in a network and provide a better understanding of their dynamic interplay (Borsboom & Cramer, 2013; Rhemtulla et al., 2017).

Recent research, although limited, has used network analysis to assess PTSD symptoms in people who have experienced earthquakes. In a cross-sectional study estimating the latent network of PTSD symptoms among earthquake survivors, the externalizing behavior dimension (i.e., irritability/anger and self-destructive/reckless behavior) has been found to have the highest centrality, and the edges between intrusion and avoidance have been found to be the strongest in the network (Li et al., 2020). The network structure of PTSD symptoms has also been examined in longitudinal studies of PTSD in earthquake survivors with various periods (Ge et al., 2019; Liang et al., 2021). For example, Liang and colleagues (2021) have observed that sleep problems showed decreasing centrality at 15 and 27 months, as compared with 3 months after the earthquake, whereas physiological cue reactivity and flashbacks became more important over time; moreover, the global connectivity of the network was stronger at 27 months post-earthquake than at 3 months and 15 months. In addition, studies are increasingly using psychological network models to investigate PTSD symptom interactions across broad classifications of trauma exposures, such as motor vehicle accidents, mud slides, and terrorist attack (Liang et al., 2021; Spitzer et al., 2022; Trachik et al., 2022; von Stockert et al., 2018). Several reviews of PTSD network analysis have consistently indicated that the symptom "amnesia" is clearly the least central symptom (Birkeland et al., 2020; Isvoranu et al., 2021). The aforementioned studies have provided novel insights into how PTSD symptoms are associated with the evolution of survivors from earthquakes, but they have several limitations. Existing studies on PTSD in earthquake survivors have focused on cross-sectional relationships between individual symptoms at single time point, thus precluding analysis of interplay and temporal directionality. Moreover, these studies have examined the PTSD network by using data from the whole samples of participants, and have neglected the longitudinal trajectories of PTSD symptoms over time, thus, precluding investigation of associations between-person and within-person networks.

The cross-lagged panel network (CLPN) analysis (Rhemtulla et al., 2017), a novel method for determining how such associations develop over time, has recently been reported. The CLPN can demonstrate how symptoms at the baseline assessments can predict symptoms at the follow-up assessments and further illustrate the causal influences between symptoms from baseline to follow-up (Funkhouser et al., 2021; pp. 6, 1325; Rhemtulla et al., 2017). Although the autoregressive paths in the CLPN may be confounded by stable individual differences (i.e., trait-like and time-invariant nature), this method is well suited for application in longitudinal panel data for modeling temporal effects among individual elements of a construct across distinct PTSD symptoms.

In summary, the present study elucidated time-variant associations between PTSD symptoms across four prototypical PTSD trajectories by using CLPN analysis, and identified which symptoms were most central to prospective prediction by computing symptom centrality indices across prototypical PTSD trajectories. In particular, because the anniversary of an earthquake can easily trigger perceptual information regarding the earthquake experience, which would in turn induce as strong stress symptoms as the original trauma did; therefore, understanding the dynamics of PTSD symptoms and their development of PTSD symptoms after the anniversary date is important (Ehlers & Clark, 2000; Fan et al., 2015). Hence, we examined the distinct trajectories of PTSD symptoms from 12 months to 24 months post-earthquake.

2. Methods

2.1. Participant and procedure

The data used in this study were a part of the Wenchuan Earthquake Adolescent Health Cohort (WEAHC) study. The WEAHC study initially surveyed 1357 adolescent survivors from one senior high school 6 months ($T_{6\ m}$; November 2008), then 12 months ($T_{12\ m}$; May 2009; 1223 survivors), 18 months ($T_{18\ m}$; November 2009; 1091 survivors), 24 months ($T_{24\ m}$; May 2010; 1109 survivors), 30 months ($T_{30\ m}$; November 2010; 861 survivors), and 10 years (T_{10y}; November 2018; 799 survivors) after the Wenchuan earthquake. Further information on sampling and data collection has been provided in earlier studies (Chen et al., 2020; Fan et al., 2017; Wang et al., 2022). Given the anniversary reaction of adolescents' PTSD symptoms (Fan et al., 2015), we included participants with follow-up at 12 months and 24 months post-earthquake to enable estimation of changes in PTSD symptoms in each individual. Hence, the final study sample consisted of 1022 participants (424 males) who were assessed at 6 months, 12 months, and 24 months post-earthquake. Adolescent survivors ranged in age from 13 to 18 years, and the mean age of 15.4 years (SD = 0.65). Targeted students filled out self-reported questionnaires, including questions on demographics, earthquake experiences, and PTSD symptoms, in classroom settings under the operationalized guidance of professional investigators from South China Normal University.

The Human Research Ethics Committee of South China Normal University granted approval for the WEAHC study, and the participating school board as well as the Chengdu Women's Federation provided their permission and support. The current study was conducted in accordance with the Helsinki Declaration revised in 1989. All participants or their guardians (as necessary) were required to sign an electronic informed consent form before the study, and t had the right to withdraw from the survey at any time.

3. Measures

3.1. Demographic and earthquake experiences

Demographic information (gender and age), and earthquake experiences (dead, missing, and/or injured family members; house damage; property loss rather than house damage; and direct witness of the tragic disaster) were collected at $T_{6\ m}$.

4. PTSD symptoms

PTSD symptoms during the prior six months were assessed at $T_{12\ m}$ and $T_{24\ m}$ with the Post-Traumatic Stress Disorder Self-Rating Scale (PTSD-SS; see Supplementary Material; Liu et al., 1998), which has been reported to have satisfactory psychometric properties among Chinese adolescents (Geng et al., 2019). Each of the 24 items of the PTSD-SS is rated on a 5-point scale ranging from 1 (not at all) to 5(extremely severe). The total score ranges from 24 to 120, with higher scores indicating more severe symptoms. A score of 50 or above was used to indicate probable clinical PTSD symptoms (Liu et al., 1998). In this study, Cronbach's alpha was 0.94 at $T_{12\ m}$ and 0.96 at $T_{24\ m}$.

5. Statistical analyses

5.1. Trajectories of PTSD symptoms

Given that bias is introduced in the network model in the general population rather than in the network models of the groups defined by the sum-score, we defined groups of individuals with and without PTSD based on a sum-score cut-off (Haslbeck et al., 2022). Four PTSD trajectories based on the cut-off value of the PTSD-SS were classified (Bonanno et al., 2008; Bonanno et al., 2012; Fan et al., 2015; pp. 0, 1242; Norris et al., 2009; Osofsky et al., 2015; Santiago et al., 2013) as follows: chronic dysfunction, delayed dysfunction, recovery, and resistance. Specifically, the resistance group consisted of individuals whose PTSD-SS scores were consistently below the cut-off value (50) of the PTSD-SS over time; those with PTSD-SS scores that exceeded the cut-off only at $T_{12\ m}$ but were below the cut-off at $T_{24\ m}$ were included in the recovery group; those with had negative PTSD symptoms at $T_{12\ m}$ but had positive PTSD symptoms at $T_{24\ m}$ were included in the delayed dysfunction group; and those with PTSD-SS scores above the cut-off value across all two-wave surveys were included in the chronic dysfunction group.

6. Temporal network

Autoregressive and cross-lagged coefficients were calculated with a series of nodewise logistic regression models to estimate CLPNs based on the R-package *glmnet* (Friedman et al., 2010; Rhemtulla et al., 2017). Autoregressive coefficients refer to the likelihood that a symptom at baseline predicts presence of the same symptom at follow-up after controlling for all other symptoms at the initial time-point, with a larger value indicating greater stability or influence of the prior time-point. Cross-lagged coefficients reflect the likelihood that a symptom at baseline predicts the presence of a different symptom at follow-up after adjustment for all other symptoms on the first occasion. According to a previous study (Funkhouser et al., 2021, pp. 13256), a LASSO (*least absolute shrinkage and selection operator*) with 10-fold cross-validation was applied to tune parameter selection to shrink small regression coefficients to exactly zero. All networks were estimated using the R-package *glmnet* and visualized with the R-package *qgraph* (Epskamp et al., 2012). Nodes in a CLPN graph represent symptoms, line thickness signifies the strength of association, and arrows reflect the estimates of cross-lagged effects.

The in-prediction (in expected influence, in-EI) and out-prediction (out expected influence, out-EI) centrality indices were calculated with the R-package *qgraph* (Epskamp et al., 2012). The in-EI is computed by summation of the values of incoming edges connected to a symptom, reflecting the proportion of variance for a given variable at follow-up that is accounted for by nodes at baseline; the out-EI is computed by summation of the values of outgoing edges connected to a symptom, indicating the effect a given node at baseline has on nodes at follow-up (Funkhouser et al., 2021; pp. 6, 1325; Rhemtulla et al., 2017).

The accuracy and stability of CLPNs were evaluated with the following steps in the R-package *boonet* (Epskamp et al., 2018). First, we tested the accuracy of edge-weights by using 95% confidence intervals (CIs) around each edge weight with nonparametric bootstrapping [1000 iterations] (Epskamp et al., 2018; Funkhouser et al., 2021; pp. 6, 1325). Subsequently, we calculated the correlation stability (CS) coefficients by using case-drop bootstrapping to determine the stability of the rank order of centrality indices. The CS ranges from 0 to 1, which should not be less than 0.25 and preferably be above 0.5 (Epskamp et al., 2018; Funkhouser et al., 2021; pp. 6, 1325). Furthermore, we examined whether the edges differed significantly from each other by testing the edge weight difference (Epskamp et al., 2018; Funkhouser et al., 2021; pp. 6, 1325). Supplementary materials provide R codes.

7. Results

7.1. Trajectories of PTSD symptoms

Fig. 1 displays the change patterns and four trajectories of PTSD symptoms, including chronic dysfunction, delayed dysfunction, recovery, and resistance. Among 1022 earthquake survivors, 112 individuals (11.0%) with PTSD-SS total scores that were consistently equal to or above the cut-off of 50 over time were classified in the chronic dysfunction group. The delayed dysfunction group (n = 37, 3.6%) was characterized by PTSD-SS total scores below the cut-off at $T_{12\ m}$ but equal to or above the cut-off at $T_{24\ m}$. The recovery group (n = 137, 13.4%) was characterized by the presence of initial PTSD symptoms but no PTSD symptoms over time. Survivors without PTSD symptoms across the two time points were classified in the resistant group (n = 736, 72.0%).

8. Temporal networks across survivors with distinct PTSS trajectories

8.1. Accuracy and stability of network parameters

The accuracy plots display small-to-moderate confidence intervals around edge weights, suggesting good accuracy for CLPN networks across the four trajectories of PTSD symptoms (Supplementary Figure 1). Similarly, the case-drop bootstrapping results (Supplementary Figure 2) revealed small-to-moderate stability for the in-EI in the resistance group and for the out-EI in the other three groups except the delayed dysfunction group. Specifically, the CS coefficients of in-EI and out-EI across four trajectories of PTSD symptoms were as follows: the CS of in-EI was 0.11, and the CS of out-EI was 0.32 in the chronic dysfunction group; the delayed dysfunction group had CSs of 0 for both in-EI and out-EI; the recovery group had a CS of in-EI of 0 and a CS of out-EI of 0.31; and the resistance group had a CS of in-EI of 0.29 and a CS of out-EI of 0.28. In addition, edge-weights difference tests (Supplementary Figure 3) revealed that these edges were significantly stronger than most other edges except edges in the delayed dysfunction group. Centrality difference tests demonstrated that these symptoms had significantly higher in-EI than other symptoms in the CLPNs in chronic dysfunction and resistance group (Supplementary Figure 4) and higher out-EI than other symptoms in three CLPNs except in the delayed dysfunction group (Supplementary Figure 5).

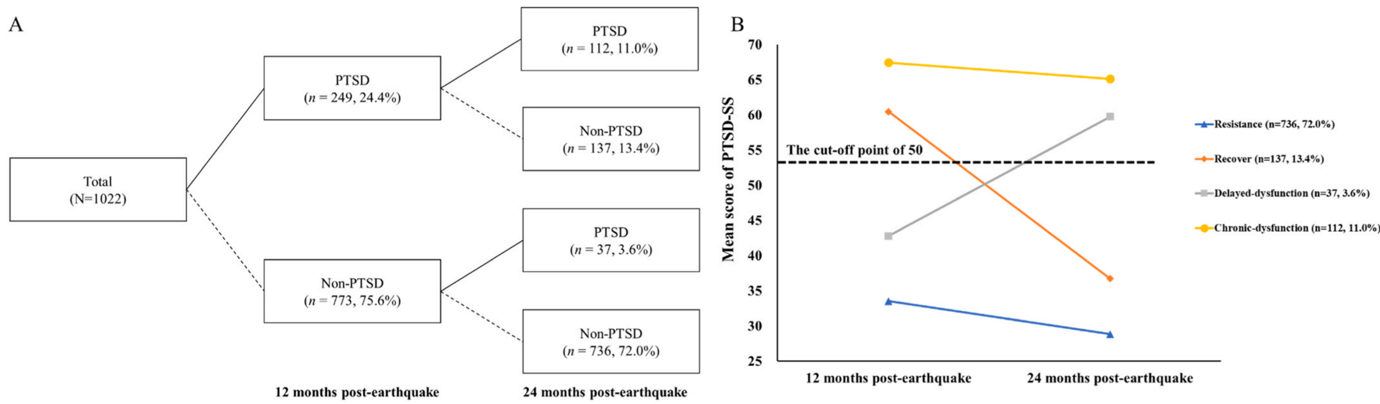

Fig. 1. The change pattern (A) and four trajectories (B) of PTSD symptoms from 12 months to 24 months post-earthquake among 1022 adolescent survivors.

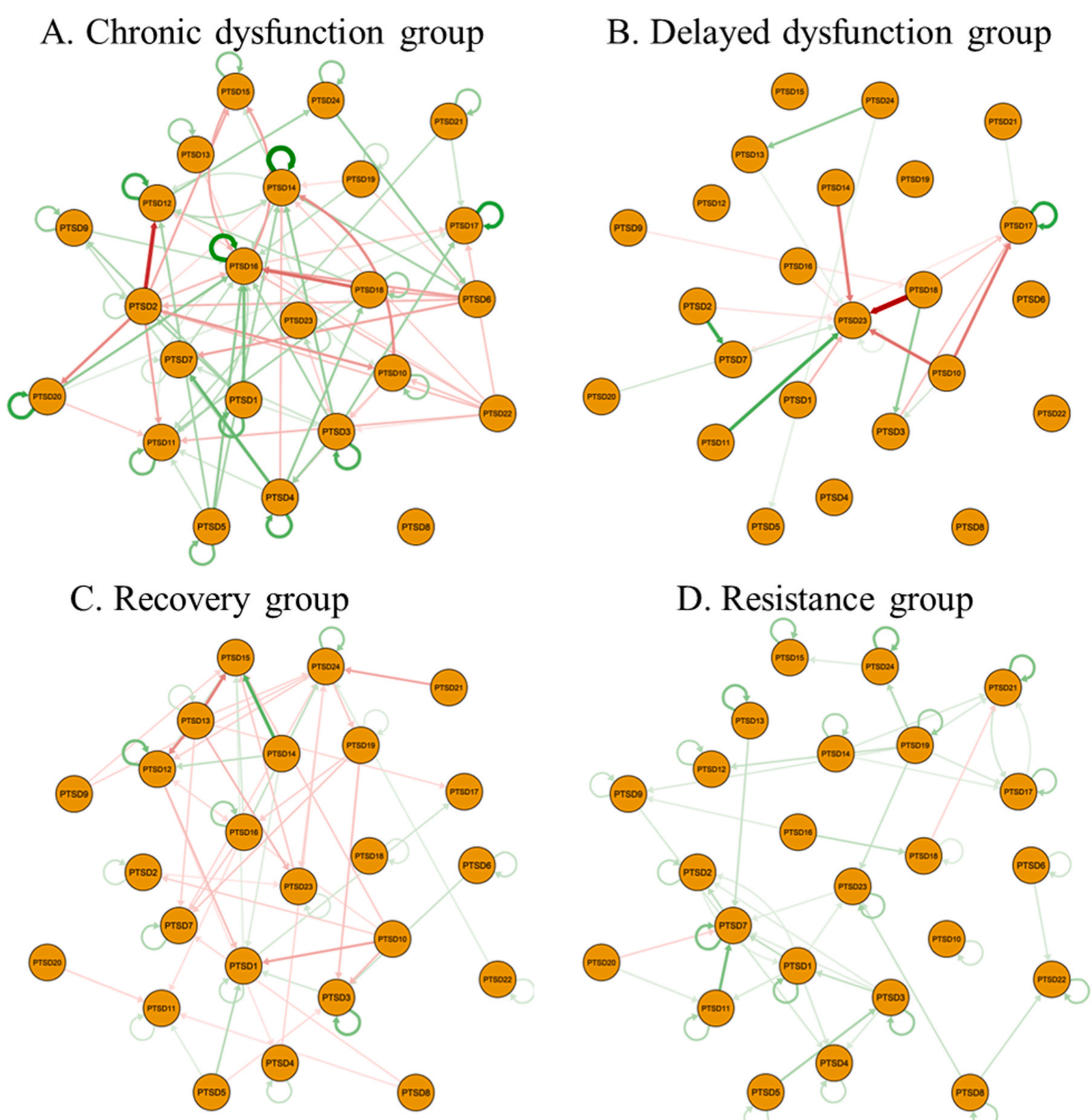

Fig. 2. Cross-lagged panel networks from 12 months to 24 months post-earthquake (A, chronic dysfunction group; B, delayed dysfunction group; C, recovery group; D, resistance group). A threshold of all edge weights was manually set to 0.05 to make the figures more interpretable. *Note:* Each curved arrow 'loop' reflects an autoregressive association; White nodes indicate depressive symptoms; Blue lines indicate positive relations, whereas red lines signal negative relations, and line thickness and boldness reflect the strength of associations.

9. Network structures

Fig. 2 shows the CLPNs between 12 months and 24 months post-earthquake in the four trajectories of PTSD symptoms. Supplementary Tables 2–5 list all edge weights. The CLPNs of PTSD symptoms (24 nodes) revealed that 53 of 133 edges in the chronic dysfunction group, 16 of 31 edges in the delayed dysfunction group, 69 of 119 edges in the recovery group, and 15 of 198 edges in the resistance group, were estimated to be below zero, indicating negative correlation between symptoms. The symptoms with the greatest autoregression coefficients were as follows: “Difficulty in study or work” (PTSD14; Edge weight = 0.41) in the chronic dysfunction group, “Dysphoria” (PTSD17; Edge weight = 0.39) in the delayed dysfunction group, “Intrusive thoughts” (PTSD3; Edge weight = 0.24) in the recovery group, and “Negative beliefs” (PTSD7; Edge weight = 0.20) in the resistance group, respectively. Additionally, the strongest cross-lagged edges in the chronic dysfunction, delayed dysfunction, recovery, and resistance groups were the edges of “Trauma-related rumination (PTSD4) → Negative beliefs (PTSD7; Edge weight = 0.22)”, “Emotional cue reactivity (PTSD2) → Negative beliefs (PTSD7; Edge weight = 0.37)”, “Difficulty in study or work (PTSD14) → Difficulty in concentration (PTSD15; Edge weight = 0.24)”, and “Exaggerated startle response (PTSD11) → Negative beliefs (PTSD7; Edge weight = 0.20)”, respectively. In addition, as shown in Table 2, correlations related to the network structures were observed between the chronic dysfunction and resistance groups ($r = 0.16$, $p = 0.006$), and recovery and resistance groups ($r = 0.10$, $p = 0.040$).

9.1. Network inference

Previous studies have indicated that these symptoms of high out-EI drive the development of psychological diseases and therefore may be potential targets for clinical intervention (Liang et al., 2022; McNally, 2016). Given the unknown availability and effectiveness of clinical interventions and the poor stability of out-EI in the delayed dysfunction

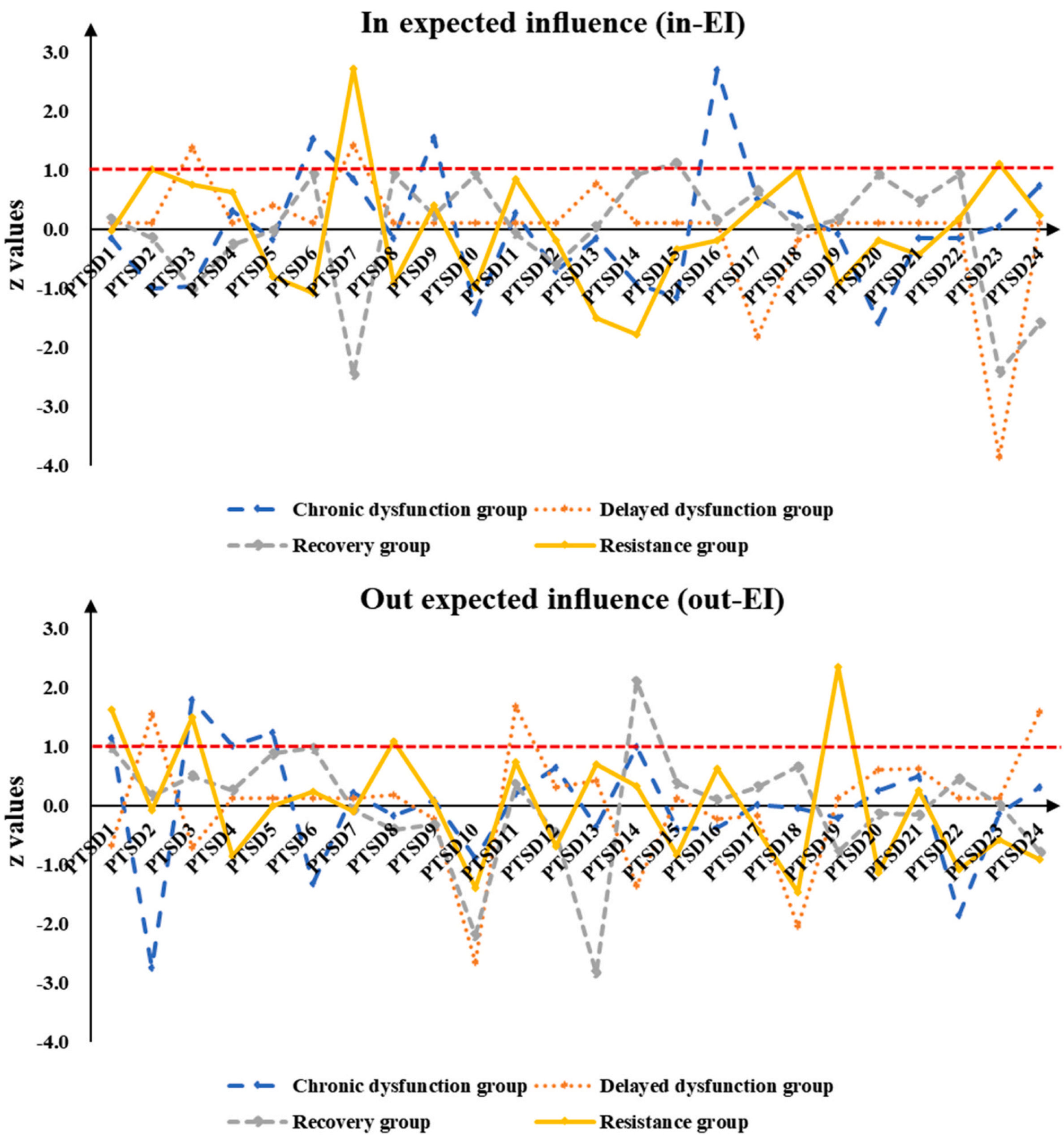

Fig. 3. Centrality estimates of in-EI (Upper) and out-EI (Lower) using z values across four trajectories of PTSD symptoms.
Note: Higher values indicate more centrality; The red line indicates the value of in-EI or out-EI equal to 1.

group, although they were determined, we do not report any findings for the centrality indices of in-EI across the four networks and out-EI in the delayed dysfunction group.

As shown in Fig. 3 and Table 1, centrality estimates reveled that the symptoms of "Intrusive thoughts" (PTSD3; out-EI = 1.79) in the chronic dysfunction group, "Difficulty in study or work" (PTSD14; out-EI = 2.10) in the recovery group, and "Physiological cue reactivity" (PTSD19; out-EI = 2.34) in the resistance group had the highest out-EI. More specifically, "Intrusive thoughts" (PTSD3) in the chronic dysfunction group at $T_{12\ m}$ positively predicted nine other PTSD symptoms at $T_{24\ m}$, such as "Difficulty in study or work" (PTSD14; Edge weight = 0.15), "Trauma-related rumination" (PTSD4; Edge weight = 0.14), and "Dysphoria" (PTSD17; Edge weight = 0.141). In terms of the recovery group, "Difficulty in study or work" (PTSD14) at $T_{12\ m}$ positively predicted four PTSD symptoms at $T_{24\ m}$, such as "Difficulty in concentration" (PTSD15; Edge weight = 0.24). In the resistance group, "Physiological cue reactivity" (PTSD19) at $T_{12\ m}$ positively predicted fifteen PTSD symptoms at $T_{24\ m}$, such as "Memory decline" (PTSD24; Edge weight = 0.11). In addition, "Nightmares" (PTSD5; out-EI = 1.24) and "Impaired in spirituality" (PTSD1; out-EI = 1.15) in the chronic dysfunction group, PTSD1 (out-EI = 1.63) and PTSD3 (out-EI = 1.49) in the resistance group were also significant centrality indicators.

10. Discussion

By utilizing network modeling on panel data from a large, population-based cohort of earthquake survivors, the current study reports the first examination of unique longitudinal relationships between symptoms across distinct trajectories of PTSD symptoms. The study revealed two main findings: first, the network structures across distinct PTSD trajectories were differed; second, the predictability of "Intrusive thoughts" on other PTSD symptoms appeared to be the strongest in the chronic dysfunction groups, whereas "Difficulty in study or work" in the recovery group and "Physiological cue reactivity" in the resistance group were strongly associated with the remission of other PTSD symptoms.

Trajectory analysis suggested that the response to the Wenchuan earthquake in adolescent survivors was likely to follow four different paths: chronic dysfunction (11.0% of the whole sample), delayed dysfunction (3.6%), recovery (13.4%), and resistance (72.0%). The four trajectories were consistent with the trajectory groups reported in other trauma populations (Bonanno & Mancini, 2012; Bonanno et al., 2012; Dikmen-Yildiz et al., 2018). However, the proportions of the four trajectory groups were not fully consistent with those in previous studies. For instance, the proportion of resilience in our study was higher than that reported(60.0%) in 330 adults who underwent emergency surgery after a severe injury, whereas the proportions of the other three trajectories were lower (recovery, 12.0%; delayed dysfunction, 6.0%; chronic dysfunction, 22.0%)(Bonanno & Mancini, 2012). These differences in proportions between our study and other studies are likely to be due to differences in screening tools, samples (clinical, community, and veteran), the type of exposure (surgery vs. earthquake), and assessment time points. Trajectory analysis indicated that a substantial proportion of survivors still experienced chronic or delayed dysfunction two years after the Wenchuan earthquake; therefore, continuous screening and treatment are necessary to enhance recovery or prevent worsening of PTSD symptoms after earthquakes.

The current study may be the first to suggest that the network structures across distinct trajectories among adolescent earthquake survivors differ. The findings not only demonstrated differences in the patterns of interaction between PTSD symptoms across the four trajectories, but also may inform health system interventions after disasters or traumatic events. To our knowledge, previous studies have tended to examine network structure of PTSD based on a whole sample (Liang et al., 2022; Schlechter et al., 2022); thus, they would ignore insight into these interactions within sub-population. Given that differences in distinct PTSD trajectories and recent evidence that it is well suited for comparing statistical network models estimated from groups defined by the sum-score (Haslbeck et al., 2022), future study can provide insight into these interactions across different sub-groups to provide individualized intervention.

For the network model within the chronic dysfunction group, the directed CLPN model revealed that the symptom "Intrusive thoughts" with the highest out-EI generally predicted other symptoms, indicating that "Intrusive thoughts" may maintain or intensify high levels of PTSD over time. This finding is consistent with those from several undirected cross-sectional networks in different populations (i.e., war survivors), which have indicated that intrusive thoughts are a central symptom of

Table 1
Centrality estimates of in-EI and out-EI using z values across four trajectories of PTSD symptoms.

Construct/nodes	Label	Chronic dysfunction group		Delayed dysfunction group		Recovery group		Resistance group	
		in-EI	**out-EI**	**in-EI**	**out-EI**	**in-EI**	**out-EI**	**in-EI**	**out-EI**
Impaired in spirituality	PTSD1	-0.16	1.15	0.11	-0.67	0.18	0.98	-0.03	1.63
Emotional cue reactivity	PTSD2	-1.01	-2.74	0.11	1.55	-0.15	0.17	1.02	-0.07
Intrusive thoughts	PTSD3	-0.97	1.79	1.38	-0.71	-1.01	0.50	0.75	1.49
Trauma-related rumination	PTSD4	0.32	1.02	0.11	0.13	-0.26	0.26	0.62	-0.86
Nightmares	PTSD5	-0.18	1.24	0.40	0.13	-0.02	0.88	-0.80	-0.01
Loss of interest	PTSD6	1.53	-1.32	0.11	0.13	0.92	0.97	-1.08	0.24
Negative beliefs	PTSD7	0.85	0.21	1.42	0.13	-2.46	-0.07	2.72	-0.09
Estrangement with relatives	PTSD8	-0.16	-0.16	0.11	0.18	0.92	-0.41	-0.91	1.09
Avoidance of thoughts	PTSD9	1.55	0.09	0.11	-0.22	0.23	-0.32	0.40	0.07
Indifferent to colleagues (students) and friends	PTSD10	-1.40	-0.89	0.11	-2.64	0.92	-2.19	-0.98	-1.40
Exaggerated startle response	PTSD11	0.27	0.19	0.11	1.68	-0.07	0.35	0.84	0.73
Sleep disturbance	PTSD12	-0.70	0.64	0.11	0.31	-0.60	-0.46	-0.18	-0.69
Guilt	PTSD13	-0.16	-0.35	0.78	0.43	0.04	-2.83	-1.50	0.70
Difficulty in study or work	PTSD14	-0.93	1.00	0.11	-1.36	0.92	2.10	-1.77	0.33
Difficulty in concentration	PTSD15	-1.15	-0.38	0.11	0.13	1.12	0.38	-0.34	-0.83
Avoidance of reminders	PTSD16	2.70	-0.38	0.11	-0.22	0.15	0.09	-0.18	0.63
Dysphoria	PTSD17	0.52	0.02	-1.81	-0.18	0.65	0.32	0.43	-0.41
Flashbacks	PTSD18	0.24	-0.03	-0.18	-2.03	0.01	0.66	0.99	-1.47
Physiological cue reactivity	PTSD19	-0.07	-0.20	0.11	0.13	0.17	-0.78	-0.93	2.34
Unprovoked aggression / impulsive behavior	PTSD20	-1.57	0.26	0.11	0.60	0.92	-0.14	-0.18	-1.14
Pessimistic	PTSD21	-0.16	0.50	0.11	0.62	0.48	-0.15	-0.43	0.26
Trauma-related amnesia	PTSD22	-0.16	-1.85	0.11	0.13	0.92	0.46	0.19	-1.07
Irritability or anger	PTSD23	0.05	-0.12	-3.85	0.13	-2.41	0.01	1.11	-0.58
Memory decline	PTSD24	0.75	0.32	0.11	1.60	-1.59	-0.78	0.23	-0.91

Note: in-EI, in expected influence; out-EI, out expected influence.

other symptom clusters within their networks (Bryant et al., 2017; Schlechter et al., 2022). Furthermore, Phillips et al. have found a higher centrality of intrusive thoughts in the high-exposure group than the low-exposure group (Phillips et al., 2018). However, other studies found that other symptoms (feeling distant or cut off from others; sleep problems) are most central (Duek et al., 2021; Liang et al., 2021). Similarly, a recent meta-analysis has conducted that no symptoms clearly play a most central role in the network (Isvoranu et al., 2021). The reasons for the differences in central symptoms may be due to differences in sample characteristics, methodological choices in the centrality metric, and the network statistical methods (Birkeland et al., 2020; Isvoranu et al., 2021). Indeed, intrusive thoughts are a prototypical symptom of PTSD (Birkeland et al., 2020) and are regarded as a threat stimulus that can easily trigger a resemblance to the perceptual information of the trauma experience, in turn, which would induce as strong PTSD symptoms as the original earthquake did (Ehlers & Clark, 2000; Hackmann et al., 2004). As time elapses after the earthquake, intrusive thoughts may be centrally associated with other symptoms in the later phase, thus potentially indicating the utility of addressing this symptom in chronic PTSD treatment.

"Difficulty in study or work" in the recovery group had the highest out-EI and the strongest associations with "Difficulty in concentration", which can be supported the identified common network structure had high intercorrelations between symptoms, as demonstrated by a meta-analysis of PTSD networks (Isvoranu et al., 2021). Although few studies have regarded "Difficulty in study or work" as the most central symptom, most previous studies have revealed that "Difficulty in concentration" was the central symptom within unidirectional PTSD networks (Bryant et al., 2017; McNally et al., 2015). A possible explanation for these findings may be that the post-earthquake environment is unsuitable for study or work and decreases concentration, which is associated with more general cognitive difficulties, diminishing the capacity to manage memories and solve problems (Bryant et al., 2017; Vasterling et al., 1998). Good conditions for working or studying are conducive to minimizing the severity of PTSD in the years following an earthquake. Table 2.

"Physiological cue reactivity" in the resistance group was the symptom with the highest out-EI centrality; similar findings have been reported in several cross-sectional networks studies among children and adolescents (Cao et al., 2019; pp. 3, 1296; Ge et al., 2019; Russell et al., 2017). Bryant et al. have also indicated that physiological cue reactivity plays a central role within the PTSD network during the acute phase in 1138 patients with traumatic injury (Bryant et al., 2017). As revealed by the conditioning theories of PTSD, psychological and physiological cue reactivity are considered to be at the core of PTSD development (Keane et al., 2006). Indeed, the body would generates a chain of rapidly occurring physiological reactions to mobilize its resources to address threatening circumstances (Kryklywy et al., 2022), thus potentially leading to other symptoms, including avoidance activities (Russell et al., 2017).

This study has several limitations that must be noted. First, the restricted type of trauma might limit the generalizability of our findings to other populations. Future replication studies sampling diverse traumatic experiences in various cultures remain warranted. Second, the centrality indices (out-EI) of these groups should be interpreted with caution for they were less than 0.5 (Epskamp et al., 2018). Although the size of the subgroups may limit the stability of the analysis, it should be noted that previous studies with larger samples (Rubin et al.:309 early adolescences, 255 middle adolescences; Funkhouser et al.:1583 T2 → T3 subsample) also found that the CS-coefficients values of in-EI/out-EI were less than 0.25 (Funkhouser et al., 2021, pp. 13256; Rubin et al., 2021). Therefore, we guess that the size of sample maybe not the key factor of the CS-coefficients. Future study can investigate the key factors of the CS-coefficients. The third limitation is the restricted availability of the causal interactions between the symptoms in CLPN models. Although the CLPN methods can distinguish the direction of causality between symptoms by using longitudinal data, the time window of the lags and a between-person level limit the ability of the current analysis to establish "causality". Fourth, we only collected part of demographics and were unable to collect social economic status data, as the survivors were students in our study. Fifth, the PTSD-SS, on the basis of DSM-IV diagnostic criteria, was used to estimate PTSD symptoms in this study. Further research could be conducted on temporal networks of PTSD symptoms based on the DSM-5 diagnostic criteria, given that three new symptoms (distorted blaming of oneself or others, persistent negative emotional state, and self-destructive/reckless behavior) were added to the diagnostic criteria for PTSD in the DSM-5 (APA, 2013).

Table 2
Correlation of the network structures between groups of distinct trajectories.

		1	2	3	4
1	Chronic dysfunction group	1			
2	Delayed dysfunction group	0.05	1		
3	Recovery group	0.02	0.07	1	
4	Resistance group	0.16 * *	0.01	0.10 *	1

11. Conclusion

Overall, significant differences in the network structures exist across distinct PTSD trajectories, indicating that a single PTSD symptom should not be expected to drive other symptoms among all earthquake survivors. In addition, our findings underscore the importance of "Difficulty in study or work" and "Physiological cue reactivity" and further suggest that "Intrusive thoughts" may influence other PTSD symptoms. Future research should investigate the causality and associations between within-person networks.

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CRediT authorship contribution statement

Zijuan Ma: Conceptualization; Formal analysis; Methodology; Software; Validation; Visualization; Roles/Writing – original draft; Writing – review & editing. **Dongfang Wang:** Writing assistance; Formal analysis; Validation; Writing – review & editing. **Xueying Fu:** Language help; Writing assistance; Writing - review & editing. **Yanqiang Tao:** Methodology; Software; Formal analysis; Validation; Writing – review & editing. **Yifan Zhang:** Formal analysis; Writing – review & editing. **Wenxu Liu:** Formal analysis; Writing – review & editing. **Fang Fan:** Conceptualization; Funding acquisition; Investigation; Project administration; Resources; Supervision; Validation; Writing – review & editing.

Declaration of competing Interest

All authors declare no conflict of interest.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.janxdis.2023.102767.

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