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ORIGINAL CONTRIBUTION

Depicting the associations between different forms of psychopathology in trauma-exposed adolescents

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Abstract

Psychiatric comorbidity in traumatized youth is prevalent, but such associations between two disorders may be confounded with other comorbid conditions. Few studies have examined the unique relationships among multiple disorders. Which disorders maximally explain the relationships between others and whether such disorders differ by sex remain largely unknown. Using a construct-level network approach, this study characterized the independent associations among nine prevalent emotional and behavioral disorders/problems evaluated by the PTSD Checklist for *DSM-5*, the Revised Children's Anxiety and Depression Scale, and the Youth Self-Report in a sample of 1181 disaster-exposed adolescents (53.9% girls; a mean age of 14.3±0.8 years). The associations were strong among the seven internalizing problems and between the two externalizing ones, but weaker between these two spectra of psychopathology. Major depressive disorder (MDD) was most strongly connected with others, maximally accounting for the associations, especially those between the two spectra. Overall and individual association strength and the connecting role of MDD were generally equivalent across sex. These findings highlight the necessity of MDD in linking comorbid forms of psychopathology in traumatized youth, and suggest MDD as a potential intervention priority in this population.

Keywords Comorbidity · Trauma · Sex · Adolescence

Introduction

Adolescence is a critical period for psychopathology emerging and evolving into chronicity [1]. Traumatic events, which are fairly common among youth [2], confer increased risk for various mental disorders in this population, such as posttraumatic stress disorder (PTSD), depression, anxiety disorders, and conduct/other externalizing behavior disorders [3]. These disorders have been theoretically assumed and empirically found to predict and/or maintain each other [4, 5], thereby partly explaining the onset and/or persistence of their comorbidity, which is associated with worse clinical outcomes [6].

Relationships between different forms of psychopathology can be explored through a novel approach, called construct-level network analysis, that depicts symptomatic/behavioral aggregates (e.g., disorders in our case) as nodes and their pairwise associations as edges [7–9]. This approach might be a way to complement theoretical hypotheses for the etiology and maintenance of co-occurring psychopathology (i.e., comorbidity) and inform clinical practice. Most previous studies of comorbidity

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in traumatized youth only focused on one association between two disorders [4]. However, growing evidence suggests that such associations are partially or even fully accounted for by another one or more comorbid conditions [10], implying that some of the prior documented relationships between disorders may be inflated or even spurious. Construct-level network analyses (especially those based on the partial correlation matrix) [11] hold clear promise to address this concern, as they can embrace a broader range of disorders and uncover the unique relationships between two disorders after adjusting for the influence of all others.

Some other studies included a number of disorders, but focused on the inequality in prevalence/severity across disorders and identified those with the highest prevalence/severity as intervention priorities [3]. Instead, construct-level network analyses afford identification of disorders most strongly connected with others, namely those with the highest centrality, in a network of co-occurring disorders. Referring to the theory and evidence of symptom-level networks [12–14], such disorders might be more important (compared to those with the highest prevalence/severity) in maintaining the connections within the network and consequently, the persistence of comorbid psychopathology.

Global strength (i.e., sum strength of all edges), a network attribute indicative of the strength of feedback loops among nodes in a network, has been theoretically and empirically linked to vulnerability to chronic psychopathology [15–17]. This attribute, when used in network analyses of co-occurring disorders would, therefore, be informative in the quantification and cross-subpopulation comparison of likelihood of enduring comorbidity after trauma.

Given this backdrop, we primarily aimed to visualize the pattern of unique relationships between nine forms of psychopathology commonly observed in trauma-exposed adolescents [i.e., PTSD, major depressive disorder (MDD), generalized anxiety disorder (GAD), obsessive compulsive disorder (OCD), social phobia (SOP), panic disorder (PD), separation anxiety disorder (SAD), aggressive behavior (AB) problem, and rule-breaking behavior (RBB) problem], via a network approach at the construct level. This approach also allowed us to identify disorders/problems highly central to the network, and to visualize whether such disorders/problems, if removed, would maximally disrupt the relationships among others. Accumulating evidence suggests that sex may moderate the co-occurrence of and/or magnitude of associations between some forms of psychopathology [18–20]. For that reason, a secondary aim of this study was to examine potential sex differences in global and individual edge strength of the network, as well as in high-centrality disorders/problems and their contributions to network connectivity.

Methods

Procedure and participants

Participants were recruited from two junior high schools located in the hardest-hit areas of the Wenchuan Earthquake. The earthquake, measuring 8.0 on the Richter magnitude scale, occurred in the west of the Sichuan basin, China on May 12, 2008, and ruptured the fault for over 240 km with surface displacements of up to nine meters. During the earthquake, nearly 70,000 people were killed, 375,000 injured, and 18,000 listed as missing; and the total direct damage was estimated at $150 billion. Data collection was conducted approximately 6.5 years after the earthquake. Investigators introduced the aim and significance of the survey in detail, and then administered self-report questionnaires to the participants in a class group format. Informed consent/assent was obtained from all participants and their guardians. This study has been approved by the Institutional Review Board of the Institute of Psychology, Chinese Academy of Sciences and has been performed in accordance with the 1964 Declaration of Helsinki and its later amendments.

A total of 1258 adolescents present at school voluntarily took part in the survey, and 77 of them were excluded from analyses in this study: 52 for not experiencing the earthquake personally (screened by the initial question "Where were you when the earthquake occurred?"), 9 for not reporting sex, and 16 for missing more than 20% items of the psychopathologically relevant measures. The final sample was comprised of 636 (53.9%) girls and 545 (46.1%) boys with a mean age of 14.3 years (SD = 0.8, range = 13–17). Ethnicity was self-identified as Qiang (768; 65.0%), Han (385; 32.6%), and other Chinese ethnicities (27; 2.3%). During the earthquake, 886 (75.0%) witnessed housing damage, 169 (14.3%) were injured, 802 (67.9%) witnessed an injury of someone, 231 (19.6%) were exposed to corpses, and 385 (32.6%) lost at least one family member. Boys were slightly older than girls (14.4 vs 14.3; t (1177) = 2.30, $p < 0.05$, Cohen's $d = 0.13$). No significant sex differences existed in ethnicity or any earthquake-related exposure (χ^2 ranged from 0.00 to 3.37, all ps > 0.05, all Cramer's Vs < 0.05).

Measures

PTSD symptoms were assessed by the PTSD Checklist for *DSM-5* (PCL-5) [21]. The PCL-5 is a self-report questionnaire consisting of 20 items scored on a 5-point Likert scale (range 0–4). The sum score of items indicates overall PTSD symptom severity. The PCL-5 has demonstrated

good psychometric properties and diagnostic utility, and received increasingly widespread use [22]. The Chinese version adapted by a two-stage process of translation and back translation has been soundly used among Chinese trauma-exposed adolescents [23]. Cronbach's αs for the PCL-5 completed referring to the Wenchuan Earthquake in this study were 0.94, 0.93, and 0.94 in the total sample, and subsamples of girls and boys, respectively.

MDD, GAD, OCD, SOP, PD, and SAD symptoms were measured by the corresponding subscales of the Revised Children's Anxiety and Depression Scale (RCADS) [24]. The RCADS is a 47-item self-report questionnaire adopting a 4-point Likert scale (range = 0–3). The sum score on each subscale denotes overall symptom severity of a particular anxiety/depressive disorder. The RCADS has demonstrated favorable psychometric properties, diagnostic utility and cross-cultural applicability [25], and its Chinese version has been previously used among Chinese traumatized adolescents [23]. Cronbach's αs for the 10-item MDD, six-item GAD, six-item OCD, nine-item SOP, nine-item PD and seven-item SAD subscales ranged from 0.81 to 0.90 in the total sample and from 0.80 to 0.90 in the subsamples of girls and boys.

AB and RBB problems were evaluated by the corresponding subscales of the Youth Self-Report (YSR) [26]—the adolescent-informant version of the Child Behavior Checklist (CBCL) screening child/adolescent behavioral problems and social competencies. The sum scores on the AB and RBB subscales whose items are rated on a 3-point Likert scale (range = 0–2) reflect overall severity of hostile/offensive and delinquent/illegal behavior problems, respectively. The YSR has been well validated across diverse cultures, including Chinese [27] and widely used in various samples, including Chinese adolescents with trauma histories [23]. Cronbach's αs for the 19-item AB and 11-item RBB subscales were 0.87 and 0.71, respectively, in the total sample; and 0.86/0.88 and 0.64/0.74, respectively, in the girl/boy subsample.

Data analysis

All descriptive statistical analyses were performed with SPSS (version 19.0). All network analyses were conducted using R (version 3.5.0). Full information, maximum likelihood (ML) procedures were used to handle the item-level missing data. The data that support the findings of this study are available from the corresponding author upon reasonable request.

Network estimation and visualization

Following Epskamp and Fried's recommendations [28], networks were estimated by the gLASSO procedure (implemented in the R package qgraph) [29] that controls for spurious connections and obtains sparse, easier interpretable networks [30], with the tuning parameter (λ) set at 0.5. Nodes represent the aforementioned nine disorders/problems; and edges represent the statistical between-node connections, each of which can be interpreted as a partial correlation between two disorders/problems with all others in the network controlled for [31]. Spearman's rank-order correlations were computed given the skewed (i.e., non-normal) distribution of total score of all measures (all Kolmogorov–Smirnov test ps < 0.001, in the total sample and subsamples of girls and boys). Network visualization based on the Fruchterman–Reingold algorithm [32] depicted stronger connections as thicker and more saturated edges, and placed nodes with stronger and/or more connections in closer proximity.

Centrality estimation

Centrality of nodes in the gLASSO network was estimated and plotted using the qgraph package. Strength (i.e., the sum of absolute values of connections of a node), which reflects how strongly that node connects directly to others in the network [33], was adopted to index the centrality of each disorder/problem. This measure of centrality has often demonstrated the most favorable stability among three common centrality measures (i.e., strength, closeness, and betweenness) in the literature [34], which was also the case in the present analysis (see supplementary Table S1). Additionally, the interpretation of betweenness and closeness in cross-sectional psychopathology networks remains unclear and thus has been criticized [35]. Following the approach introduced by McNally et al. [36], Pearson correlation between strength and standard deviation for each node was calculated, so as to exclude the possibility that differential variability in disorder/problem severity has distorted conclusions about node strength [37].

Accuracy and stability estimation

Two main analyses evaluating the robustness and interpretability of the gLASSO network were conducted using the R package bootnet (number of bootstraps = 1000) [34]. (1) To assess edge-weight accuracy, bootstrapped 95% confidence intervals (CI) were drawn and bootstrapped difference tests were performed for edge weights. Higher stability is favored by fewer overlaps among those CIs and more significant between-edge differences. (2) To assess centrality stability, the correlation stability coefficient (*CS* coefficient) was computed to quantify the maximum proportion of cases/nodes that can be dropped to retain, with 95% probability, a high correlation ($r > 0.7$) with the original centrality. The *CS* coefficient should be at least 0.25 and preferably above 0.5 for the order of centrality to be stable and interpretable [34].

Bootstrapped difference tests were also applied to determine whether nodes with higher centrality differed significantly from lower centrality ones.

Elucidation of specific nodes' contributions to network connectivity

To explicitly present how necessary each node is in maintaining the connections within the network, a series of simulated networks with specific nodes controlled for, in which edges represented partial correlations that statistically controlled for the variance associated with specified individual nodes, were computed and compared with a baseline network estimated from a zero-order correlation matrix, as per Anker et al.'s procedure [7]. Networks are visualized using the Fruchterman–Reingold algorithm (implemented in the qgraph package). To facilitate visualization of meaningful relationships between disorders/problems in the network, edges under 0.10 (i.e., representing trivial correlations) [38] were omitted from the network.

Examination of sex differences

The preceding analyses were re-conducted separately for girls and boys to examine potential sex differences in the main findings. To facilitate visual comparison, an identical layout of nodes according to the average position across sex was imposed (using the average Layout function); and minimum and maximum edge values were set at 0 (default) and 0.50 (the strongest identified edge), respectively, for the gLASSO networks in both sexes. In addition, the R package Network Comparison Test [39], evaluating the null hypothesis of invariance between two networks estimated by the gLASSO procedure (the EBIC hyperparameter assigned to 0.5) across randomly regrouped permutations of individuals (number of permutations = 1000), was used to determine whether global strength (i.e., the absolute sum of all edges in the network) and individual edge strength differed significantly by sex.

Results

The mean levels of each disorder/problem in the total sample and subsamples of girls and boys are presented in Table 1. All disorders/problems except for AB problem significantly differed in the overall severity (i.e., sum score) as a function of sex. Girls had higher mean levels of all internalizing problems especially SAD and SOP (approaching a medium effect) compared with boys, whereas boys scored higher than girls only on RBB problem (approaching a medium effect).

Network, centrality, and their accuracy and stability

The gLASSO network of comorbid psychopathology in the total sample is shown in Fig. 1a. Seven internalizing problems (i.e., PTSD, MDD, GAD, OCD, SOP, PD, and SAD) were located separately from two externalizing problems (i.e., AB and RBB), although several connections existed between these two clusters. Despite the overlaps among the 95% CIs of edge weights (see supplementary Fig. S1, panel A), considerable non-overlapping CIs and numerous significant between-edge differences (see supplementary Fig. S2, panel A) suggest that the accuracy of estimated edge weights in this network can be deemed acceptable.

Node strength centrality of each disorder/problem is plotted in Fig. 1b, showing that MDD was the most strongly connected node in the network. The stable and interpretable

Table 1 Mean levels of disorders/problems in the total sample and subsamples of girls and boys and sex comparisons

	Total	Girls	Boys	Independent sample *t* test		
	M (SD)			t^a	*p*	Effect size (Cohen's *d*)
PTSD	11.8 (11.1)	12.4 (11.2)	11.1 (11.0)	2.03	< .05	0.12
MDD	6.4 (5.4)	7.0 (5.7)	5.7 (5.0)	4.04	< .001	0.23
GAD	5.2 (4.1)	5.9 (4.2)	4.3 (3.7)	6.92	< .001	0.40
OCD	3.6 (3.5)	3.9 (3.6)	3.3 (3.3)	2.88	< .01	0.17
SOP	8.5 (5.6)	9.6 (5.6)	7.2 (5.2)	7.62	< .001	0.44
PD	5.2 (5.0)	5.7 (5.3)	4.5 (4.6)	4.06	< .001	0.24
SAD	5.2 (4.2)	6.0 (4.3)	4.2 (3.9)	7.66	< .001	0.45
AB	7.9 (5.4)	7.6 (5.1)	8.2 (5.7)	− 1.71	> .05	0.10
RBB	3.1 (2.6)	2.6 (2.2)	3.7 (2.8)	− 7.58	< .001	0.45

PTSD post-traumatic stress disorder, *MDD* major depressive disorder, *GAD* generalized anxiety disorder, *OCD* obsessive–compulsive disorder, *SOP* social phobia, *PD* panic disorder, *SAD* separation anxiety disorder, *AB* aggressive behavior problem, *RBB* rule-breaking behavior problem

[a]Positive/negative *t* values indicate that girls have higher/lower mean levels than boys

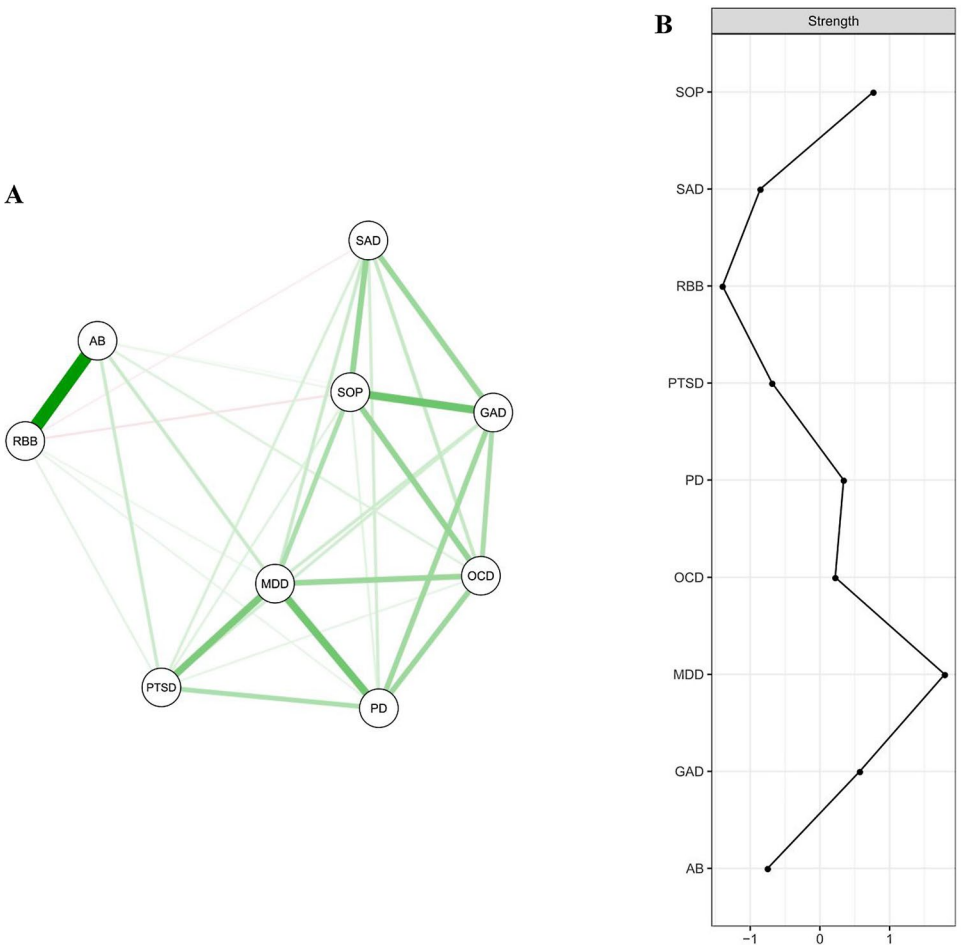

Fig. 1 GLASSO network of comorbid psychopathology (**a**) and standardized estimates of node strength centrality (**b**) in the total sample. Nodes represent disorders/problems, and edges represent partial correlations between nodes. Edge thickness and saturation indicate the strength of pairwise connections, and edge color indicates the correlation valence (green = positive; red = negative). *PTSD* post-traumatic stress disorder, *MDD* major depressive disorder, *GAD* generalized anxiety disorder, *OCD* obsessive–compulsive disorder, *SOP* social phobia, *PD* panic disorder, *SAD* separation anxiety disorder, *AB* aggressive behavior problem, *RBB* rule-breaking behavior problem

order of this centrality is indicated by its *CS* coefficients that approached or exceeded the preferable value of 0.5 (see supplementary Table S1). MDD's highest centrality is further supported by the bootstrapped difference test revealing that this node was statistically stronger than all the others (see supplementary Fig. S3, panel A). Node strength and variance were not correlated ($r = -0.01$, $p > 0.05$), which implies that differential variability across disorders/problems does not pose a problem for interpreting this centrality. Given the negative edges (i.e., SOP–RBB and SAD–RBB) in the network, supplementary analyses calculated the sum of raw values of each node's connections (using the R package networktools) [40], and yielded an extremely high correlation ($r = 0.95$, $p < 0.001$) between this index and strength, suggesting negligible influence of these negative edges on the present estimates of centrality.

The contributions of specific nodes to network connectivity

The baseline network and simulated networks after controlling for specific nodes are shown in Fig. 2. Controlling for MDD resulted in the most marked reduction in network connectivity (Table 2). With MDD controlled for (Fig. 2c), externalizing problems were nearly isolated from internalizing ones; and the connections among internalizing problems, especially those involving PTSD (with an average reduction of 64.0%), were largely weakened. Controlling for other internalizing problems (Fig. 2b, d–h) resulted in a smaller amount of reduced connectivity within the internalizing spectrum and between the internalizing and externalizing spectra. Controlling for AB or RBB problem (Fig. 2i, j) resulted in minimal reduction of the connections among internalizing problems. AB problem accounted for the vast majority of covariance between RBB and internalizing problems, rendering the corresponding connections eliminated. RBB problem, however, showed no such effect on the connections between AB and internalizing problems.

Consistency across sex

A similar pattern of findings held across sex. In particular, MDD exhibited the highest centrality in the networks of both girls and boys (Fig. 3), which is further verified by the bootstrapped difference tests (see supplementary Fig. S3, panels B and C). Acceptable accuracy of edge weights

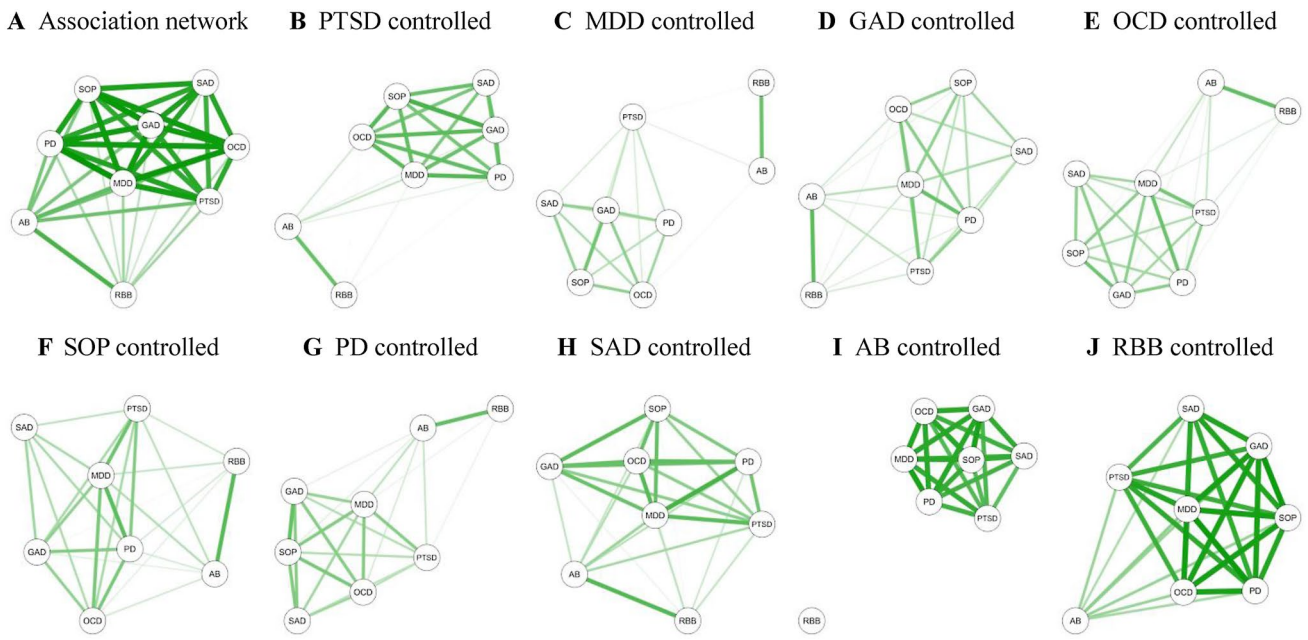

Fig. 2 Association network of comorbid psychopathology (**a**) and networks after controlling for PTSD (**b**), MDD (**c**), GAD (**d**), OCD (**e**), SOP (**f**), PD (**g**), SAD (**h**), AB (**i**), and RBB (**j**) in the total sample. Nodes represent disorders/problems, and edges represent zero-order correlations (in **a**) or partial correlations between nodes after controlling for specific nodes (in **b**–**j**). Edge thickness and saturation indicate the strength of pairwise connections, and edge color indicates the correlation valence (all edges were positive and shown in green). Edges under 0.10 were omitted from the network to facilitate visualization of meaningful relationships. Maximum edge value was set at 0.80 (the strongest edge identified across networks) to implement comparison of edge thickness and saturation across networks. *PTSD* post-traumatic stress disorder, *MDD* major depressive disorder, *GAD* generalized anxiety disorder, *OCD* obsessive–compulsive disorder, *SOP* social phobia, *PD* panic disorder, *SAD* separation anxiety disorder, *AB* aggressive behavior problem, *RBB* rule-breaking behavior problem

(see supplementary Fig. S1, panels B and C and supplementary Fig. S2, panels B and C) and stability of node strength centrality (see supplementary Table S1) are proven for both networks. No significant correlation was found between node strength and variance ($r = 0.28/-0.17$ in girls/boys, $p > 0.05$). The specific nodes' effects were also congruent between girls and boys: controlling for MDD substantially weakened the connections among others, and almost isolated externalizing problems from internalizing ones; and RBB problem was nearly isolated from internalizing problems with AB problem controlled for (Fig. 4 and Table 2). The NCT test indicated sex invariance in global strength (difference = 0.07, $p > 0.05$) and individual edge strength (all differences < 0.16, all ps > 0.05).

Discussion

This exploratory study is the first to characterize the associations among a broad range of disorders/problems from a construct-level network perspective in a trauma-exposed youth sample. The associations were found to be strong within the internalizing and externalizing spectra of psychopathology, but weaker between these two spectra. MDD, the syndrome most strongly connected with others, maximally explained the associations especially those between the two spectra. The strength of overall and individual associations was invariant for girls and boys, and the role of MDD in linking others was roughly consistent across sex.

Despite the abundant studies on relationships between two disorders/problems, whether such relationships are confounded with other comorbid conditions remains unsettled. Using partial correlation network analysis, this study detected several strong associations indicative of unique relationships among the seven internalizing problems and between the two externalizing problems. This suggests that disorders/problems belonging to the same spectrum of psychopathology are directly connected and may have interactions with each other [5, 41]. In contrast, most of the associations between internalizing and externalizing problems were negligible in this study. While there has been substantial evidence linking these two spectra of psychopathology [20, 42, 43], a recent study found no significant association of PTSD with externalizing problems after controlling for other internalizing problems including depression and anxiety [10]. Extending this, our finding suggests that internalizing problems, especially those involving anxiety may have limited direct associations with externalizing problems. Future

Table 2 Reduction in the strength of edges within and between the internalizing and externalizing spectra after controlling for specific disorders/problems (%)

	Within internalizing[a]	Within externalizing	Between internalizing and externalizing[a]	All[a]
Total sample				
PTSD	30.3	13.6	65.3	44.7
MDD	53.9	14.9	82.7	64.8
GAD	48.1	8.8	54.4	49.4
OCD	44.8	11.0	63.1	51.5
SOP	45.1	7.3	47.9	44.9
PD	45.5	12.1	64.9	52.6
SAD	32.3	5.9	34.3	32.2
AB	10.7	–	87.8	30.0
RBB	3.9	–	20.6	8.1
Subsamples of girls and boys[b]				
PTSD	35.0/26.3	15.1/14.8	63.7/54.2	46.6/37.8
MDD	52.5/55.6	16.8/17.3	78.3/74.9	62.3/62.5
GAD	49.4/45.0	10.9/13.9	53.9/59.3	50.0/50.0
OCD	44.9/46.4	12.5/12.1	60.8/53.1	50.5/48.1
SOP	46.3/43.0	10.8/11.3	56.4/48.5	49.4/44.2
PD	42.9/47.8	13.4/15.0	59.9/61.8	49.1/52.6
SAD	26.5/39.0	7.0/12.1	29.9/50.6	27.3/43.0
AB	10.9/12.4	–	77.5/72.9	27.5/27.5
RBB	4.5/6.6	–	22.1/29.2	8.9/12.3

PTSD post-traumatic stress disorder, *MDD* major depressive disorder, *GAD* generalized anxiety disorder, *OCD* obsessive–compulsive disorder, *SOP* social phobia, *PD* panic disorder, *SAD* separation anxiety disorder, *AB* aggressive behavior problem, *RBB* rule-breaking behavior problem

[a]Means were calculated

[b]Values on left/right are for girl/boy subsample

studies would profit from examining how and why cross-spectrum disorders/problems are associated indirectly and probably through their comorbid conditions.

MDD, having the strongest connections with others in this study, maximally accounted for the associations between co-occurring disorders/problems. Regarding the covariance among internalizing problems, one possible explanation for its reduction by partialling out MDD variance is that depression may mediate the links between these problems (e.g., the PTSD–GAD link) [4, 44]. An alternative explanation is that depression may contain a substantial number of components shared by these problems (e.g., negative affectivity) [45]. Of note, MDD, in particular, explained such covariance that involved PTSD. This suggests that PTSD may interact with other internalizing problems mostly through depression, or alternatively, may share the components responsible for its links to other internalizing problems with depression most largely. On the other hand, the between-spectrum covariance was also largely accounted for by MDD. Likewise, this can be interpreted as depression's mediating effect between internalizing and externalizing problems (e.g., between anxiety and conduct disorders) [46], or as indicating that depression may capture the components shared by these two spectra of psychopathology (e.g., irritability) [47]. Also noteworthy is that AB problem mostly explained the covariance between RBB problem, as another form of externalizing psychopathology, and internalizing problems. This finding, combined with those concerning MDD, suggests that depression and aggression may constitute pathways that connect internalizing and externalizing problems. However, the nature of such pathways is up for debate (e.g., a causal mediator, a common cause, or a common outcome of two others), calling for more in-depth investigations.

Although sizeable differences existed between girls and boys in their psychopathology levels, the associations among disorders/problems were equivalent across sex. This equivalence is somewhat unexpected, given prior findings of sex differences in such associations [18–20]. It should be noted, however, that each association compared here was restricted to unique covariance net of all others. The previously reported differences may be attributed, at least partly, to sex differential variance in some other disorders/problems not considered. Further studies are warranted to adequately address the stability or disparity of disorder/problem connectivity across sex.

Our findings have potential implications for clinical practice. We found that the strength of associations among disorders/problems was globally comparable between girls

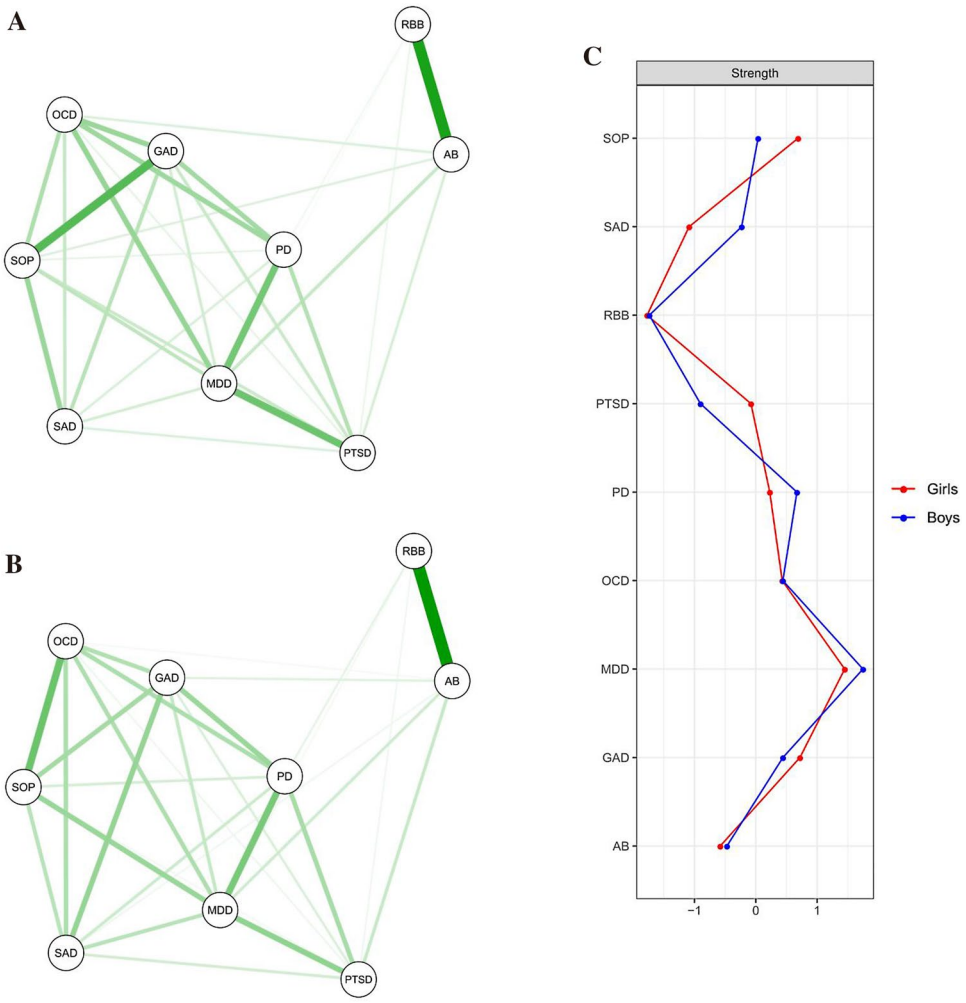

Fig. 3 GLASSO networks of comorbid psychopathology in the subsamples of girls (**a**) and boys (**b**) and standardized estimates of node strength centrality (**c**). Nodes represent disorders/problems (identical layout of nodes was imposed), and edges represent partial correlations between nodes. Edge thickness and saturation indicate the strength of pairwise connections (minimum and maximum edge values were set to be equal across sex), and edge color indicates the correlation valence (all edges were positive and shown in green). *PTSD* post-traumatic stress disorder, *MDD* major depressive disorder, *GAD* generalized anxiety disorder, *OCD* obsessive–compulsive disorder, SOP social phobia, *PD* panic disorder, *SAD* separation anxiety disorder, *AB* aggressive behavior, *RBB* rule-breaking behavior problem

and boys. This indicates that the two sexes may not differ substantially in their vulnerability to chronic comorbidity [15–17]. Accordingly, boys with comorbid psychopathology following trauma, albeit at a generally lower level compared to girls, may also deserve prompt intervention. Of the nine disorders/problems, MDD was identified as the one most essential to the between-syndrome associations and presumably, the maintenance of comorbidity [12–14] in both girls and boys. This disorder may thus be a priority for treatment of traumatized youth of both sexes. Nevertheless, due to the cross-sectional nature of this study, causal inferences cannot be made, and therefore, such priorities still await verification by longitudinal studies.

Findings of this study should be interpreted in the light of its limitations. First, we used a non-clinical sample exposed to a specific traumatic event (i.e., a disaster). Replications in clinical and/or mixed trauma samples are required before more general conclusions can be drawn. Second, the assessment of psychopathology relied solely on self-report measures. Emerging evidence has suggested the stability of network estimations (e.g., between-variable associations) across assessment modality (i.e., self-report vs. clinical interview), despite the higher variable scores in self-reports [48]. Nonetheless, our findings still need to be replicated using clinical interviews or parent/teacher report measures. Third, post-earthquake life experiences that have been found to influence post-trauma psychopathology [49] were not assessed in this study. Future studies are encouraged to examine whether those experiences moderate the presence/strength of associations between post-trauma disorders/problems. Fourth, our inclusion of a limited number of disorders/problems might leave out some others potentially central to the network. It would, therefore, be worthwhile in further studies to include additional disorders/problems especially those in the externalizing spectrum (e.g., substance use disorder). Fifth, comorbid disorders/problems were represented at the construct level as opposed to the symptom level. This reflected our intention to characterize their relationships at the same theoretical and empirical level mostly used in the pertinent literature, as well as the methodological concerns about overlapped wording in some items for one construct and insufficient sample size given the huge number of parameters

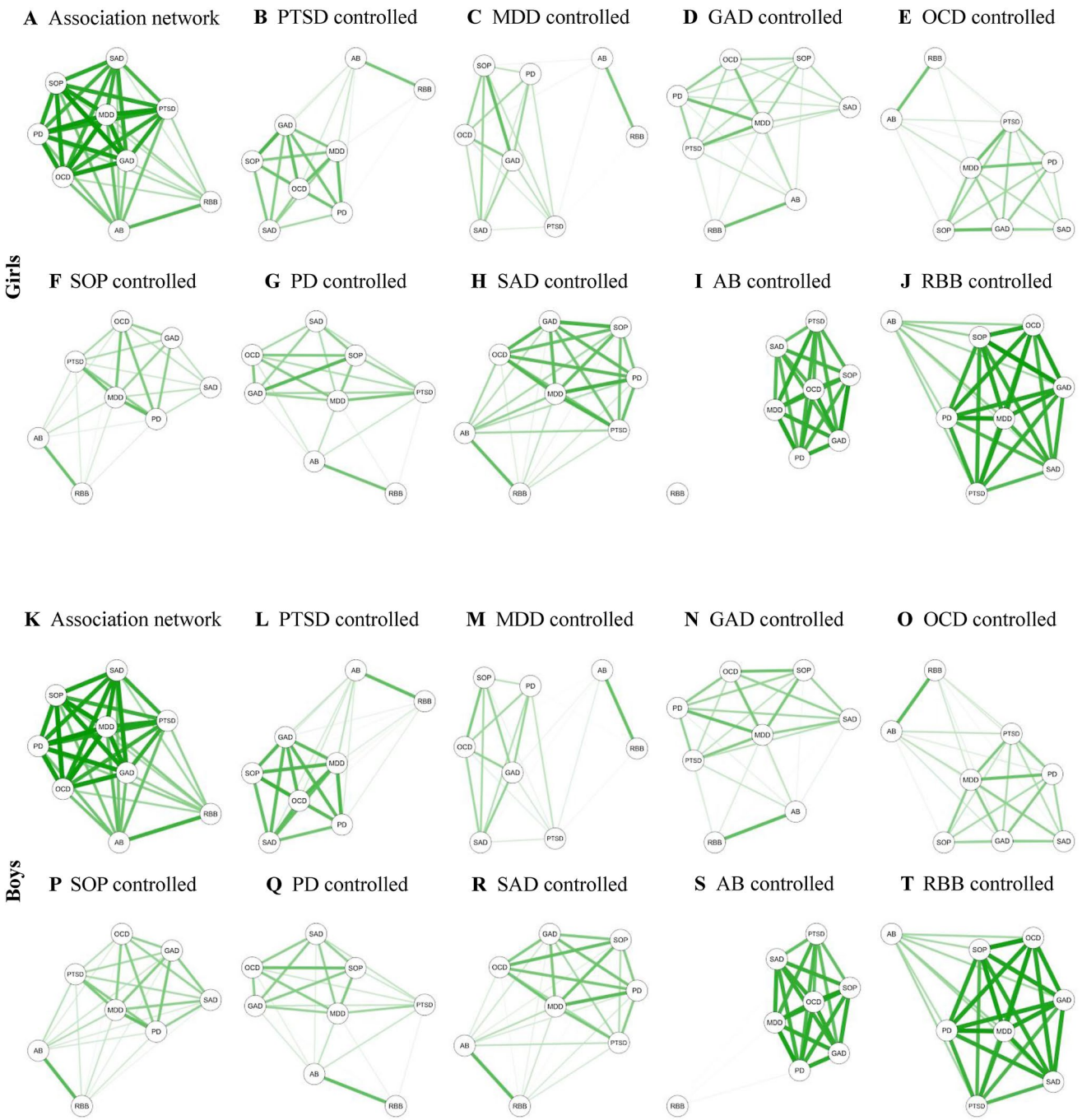

Fig. 4 Association network of comorbid psychopathology (**a**, **k**) and networks after controlling for PTSD (**b**, **l**), MDD (**c**, **m**), GAD (**d**, **n**), OCD (**e**, **o**), SOP (**f**, **p**), PD (**g**, **q**), SAD (**h**, **r**), AB (**i**, **s**), and RBB (**j**, **t**) in the subsamples of girls (top panels) and boys (bottom panels). Nodes represent disorders/problems (identical layout of nodes was imposed across sex), and edges represent zero-order correlations (in **a** and **k**) or partial correlations between nodes after controlling for specific nodes (in **b**–**j** and **l**–**t**). Edge thickness and saturation indicate the strength of pairwise connections, and edge color indicates the correlation valence (all edges were positive and shown in green). Edges under 0.10 were omitted from the network to facilitate visualization of meaningful relationships. Maximum edge value was set at 0. 81 (the strongest edge identified across networks) to implement comparison of edge thickness and saturation across networks. *PTSD* post-traumatic stress disorder, *MDD* major depressive disorder, *GAD* generalized anxiety disorder, *OCD* obsessive–compulsive disorder, *SOP* social phobia, *PD* panic disorder, *SAD* separation anxiety disorder, *AB* aggressive behavior problem, *RBB* rule-breaking behavior problem

to be estimated at the symptom level (i.e., 97 items and 4656 pairwise association parameters). Future studies, however, would undoubtedly benefit from estimation of symptom-level networks and identification of symptoms most crucial to comorbidity. Finally, as precedingly discussed, causal relationships between variables examined here cannot be inferred from our analyses of cross-sectional data. Longitudinal analyses are thus warranted to uncover how disorders/problems interact over time in a dynamic network.

Conclusion

In closing, this study provides the first depiction of associations between comorbid forms of traumatized youth's psychopathology using a construct-level network approach of burgeoning interest. The findings suggest that for both girls and boys, MDD may largely explain the maintenance of comorbidity following trauma, and may thus deserve more attention by clinicians. This study encourages more network analyses of comorbidity which have the potential to yield novel and important insights into this common, but inadequately understood, phenomenon in psychopathology.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This study has been approved by the Institutional Review Board of the Institute of Psychology, Chinese Academy of Sciences and has been performed in accordance with the 1964 Declaration of Helsinki and its later amendments.

Informed consent Informed consent/assent was obtained from all participants and their guardians.

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