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Research paper

Hierarchical network structure: A novel approach to conceptualising ICD-11 Complex PTSD using a general population sample from Africa

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ABSTRACT

Background: Investigations have sought to model the structure of ICD-11 Complex PTSD (CPTSD) using factor analytic models, finding support for higher-order domains representing PTSD and Disturbances in Self Organisation (DSO). Network analysis has alternatively modelled CPTSD through dimensional symptom associations.
Methodology: This study investigated the structure of CPTSD leveraging a novel approach, Hierarchical Exploratory Graph Analysis, using African general population samples ($N = 2524$).
Results: The hierarchical graph model was estimated identifying a structure comprising six lower-order communities, indicative of ICD-11 CPTSD symptom domains, and two higher-order communities, indicative of PTSD and DSO. Results indicate the superiority of the hierarchical model, confirming the conceptualisation of ICD-11 PTSD and CPTSD symptom groupings.
Limitations: The cross-sectional nature of these data, and novelty of the methods used prompt calls for additional investigation to support these findings.
Conclusions: Hierarchical Exploratory Graph Analysis may offer a valuable means to better understanding the complexity of CPTSD symptomology through a novel network modelling approach. Relationships between Sense of Threat and Affect Dysregulation may serve as bridging symptoms between PTSD and DSO difficulties. These may be prioritised as the therapeutic targets for CPTSD. This pioneering approach using EGA, offers new insights into the intricate structure of CPTSD, potentially informing the use of assessments and interventions across diverse populations.

1. Introduction

Several studies have delved into the structural aspects of the new ICD-11 definition of Post-Traumatic Stress Disorder (PTSD) and Complex PTSD (CPTSD) as "sibling" disorders that are structured hierarchically. Latent factorial and class/profile analyses were conducted using the International Trauma Questionnaire (ITQ), and have distinguished CPTSD from PTSD, both quantitatively and qualitatively (Böttche et al., 2018; Hyland et al., 2017a). These foundational works laid the groundwork for assessing the structural validity of the PTSD and CPTSD through various factor analysis models (Hyland et al., 2017a). Subsequent reviews, such as the work of Redican et al. (2021), synthesized latent variable based structural models and showed the concurrent validity of first-order and higher-order factor models in understanding CPTSD.

In parallel, the Psychometric Network Analysis approach has emerged as a novel approach that is focusing on dimensional symptom interactions (Borsboom et al., 2021). Noteworthy contributions by Gilbar (2020), Karatzias et al. (2020), Rossi et al. (2022), and Levin et al. (2021) exemplify the application of this approach, highlighting the interplay and dependencies among symptoms within the CPTSD spectrum. The network method has given us the perspective of the subtle interaction between symptoms, which also eased the understanding of groups of symptoms that cluster together. This approach involves algorithmic detection of internal organisation of symptoms, allowing for the identification of meaningful grouping and processes (Yang et al.,

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2016). An example of this is found in prior traditional network analysis of ICD-11 (C)PTSD supporting a two communities in a first-order structure where symptoms were clustered in 'PTSD' vs. 'DSO' communities (McElroy et al., 2019).

This above mentioned first-order network models are tested in Exploratory Graph Analysis (EGA; Christensen and Golino, 2021) which has gained attention as network graphical approach, offering potential superiority over traditional Factor Analysis (Christensen and Golino, 2021; Golino and Epskamp, 2017) and Principal Component Analysis (PCA), particularly in explaining more variance in the data (Peralta et al., 2020). Relying on Network psychometrics, EGA may be thought of as a factor retention, or data reduction, method (Golino and Epskamp, 2017). Firstly, EGA estimates the partial correlations between the variables by fitting a GGM with the GLASSO regularization and then applies a community detection algorithm for weighted networks to classify items into clusters. Usually, the clustering is achieved by maximizing modularity, an index measuring the extent to which nodes within a cluster are more connected than between clusters, all though remain in a single-level structure. A recent simulation study has however highlighted that EGA may be influenced by the presence of cross-loading, i.e. nodes associated with more than one community, thus perform poorer compared to Eigenvalue methods (Brandenburg and Papenberg, 2024). Hierarchical Exploratory Graph Analysis (hierarchical EGA) may address this in part through modelling generalized bifactor clustering of node communities at first- and second-order levels; as cross-loading may be modelled partially by higher-order community clustering offering a closer fit and better representation of complex systems.

The hierarchical EGA approach offers a novel methodology incorporating an alternative variation to a popular clustering algorithm called Louvain (Blondel et al., 2008) to detect lower and higher order factors in data (Jiménez et al., 2023). While the traditional EGA technique identifies only dimensions or clusters/communities that are in a single level, hierarchical EGA allows for identification of single order dimensions as first-order structure, and higher order general factors. One benefit of modelling hierarchical structures within networks is that the complexity of the associations between variables are represented at each level of the hierarchy, allowing for correlations between each node to be represented in the model and maintaining a more complete representation of the examined phenomenon from the bottom-up (Samo et al., 2023).

Jiménez et al. (2023) demonstrate via simulation that hierarchical EGA may outperform the original EGA approach as well as traditional factor analytic techniques such as parallel analysis for detecting high-order factors. Hierarchical EGA has been demonstrated not only to perform optimally in terms of accuracy, precision, and robustness for the conditions most likely to be encountered in practice, but also provides a classification of items into factors, offering a richer dimensionality assessment that can be easily compared with the theoretical expectations of the factor structure (Jiménez et al., 2023).

The Hierarchical Network approach remains untested for this purpose in investigation of traumatic stress, and contemporary advances in hierarchical network science may contribute a novel and comprehensively informed model of CPTSD. The theoretically suggested hierarchical bifactor structure of ICD-11 CPTSD makes this approach ideal for testing and further validation of the disorder; allowing for exploration of potential higher order PTSD and DSO communities, the interactions between them, and interactions between the nodes in the first order symptom network structure. Given the groundwork laid by Levin et al. (2021) and McElroy et al. (2019) through symptom network analysis which rely on the traditional network structures, the present study aims to further explore the same dataset utilizing hierarchical EGA methodology within this specific demographic context of unique African samples.

Given the sum of prior evidence drawn from factor analytic and network perspectives two study hypotheses are put forward in this investigation of CPTSD network structure:

H1. Lower-order network structure estimation will reveal communities representative of PTSD and DSO symptoms.

H2. Hierarchical network structure estimation will unveil higher-order communities indicative of PTSD and DSO, along with lower-order communities representing specific CPTSD symptom domains.

2. Methodology

2.1. Data & sample

This study analysed survey data drawn from three African countries; Ghana, Kenya, and Nigeria ($N = 2524$ participants). These data were collected using internet panel surveying recruiting samples approximately representative of age and gender distribution in each country based on census data. Participants were eligible to participate in this study if they had current residential status of any of the three nations previously listed, aged 18+, and possessed sufficient English proficiency to respond to survey measures. Notably while a number of languages are spoken in these nations English is an official language of each, also having a sizable population of primary English speakers (Oluwole, 2021). The characteristics of this sample are reported in brief herein, and further information on this sample and procedure is provided by Ben-Ezra et al. (2020) and Levin et al. (2021).

2.2. Measures

Basic demographics were measured using a bespoke inventory recording participant location (of three countries included in this survey), age, marital status, employment status, and educational attainment.

Lifetime trauma exposure was assessed using the Life Events Checklist (LEC-5; Weathers et al., 2013). The LEC-5 is a widely used standardized list of potentially lifetime exposure to traumatic events. This inventory is comprised of 16 events originally determined to meet the DSM-5 PTSD Criterion A, "*The person was exposed to: death, threatened death, actual or threatened serious injury, or actual or threatened sexual violence*" (Weathers et al., 2013). In the current study each item required a binary (Yes|No) response to record if the respondent had ever experienced that event.

ICD-11 (C)PTSD symptomology was measured using the International Trauma Questionnaire (ITQ; Cloitre et al., 2018). The ITQ contains 12 items detailed in Table 1; 2 per symptom cluster, assessing symptoms domains of PTSD (Re: Re-experiencing, Av: Avoidance, SoT: Sense of Threat) and Disturbances in Self Organisation (Ad: Affect Dysregulation, NSC: Negative Self Concept, DR: Disturbed Interpersonal Relationships) in line with ICD-11 criteria (Cloitre et al., 2018). All items are rated on a 5-point Likert scale indicating the extent to which respondents are distressed by these symptoms ranging from 0 "*Not at all*" to 4 "*Extremely*". Internal reliability was shown to be good in the current study sample for

Table 1
Codes and question text for International Trauma Questionnaire items.

p1	Having upsetting dreams that replay part of the experience or are clearly related to the experience?
p2	Having powerful images or memories that sometimes come into your mind in which you feel the experience is happening again in the here and now?
p3	Avoiding internal reminders of the experience (for example, thoughts, feelings, or physical sensations)?
p4	Avoiding external reminders of the experience (for example, people, places, conversations, objects, activities, or situations)?
p5	Being "super-alert", watchful, or on guard?
p6	Feeling jumpy or easily startled?
c1	When I am upset, it takes me a long time to calm down
c2	I feel numb or emotionally shut down.
c3	I feel like a failure.
c4	I feel worthless.
c5	I feel distant or cut off from people.
c6	I find it hard to stay emotionally close to people

the overall ITQ (α = 0.89), and for the PTSD (α = 0.85) and DSO (α = 0.89) subscales.

2.3. Data analytic plan

Network analysis explores the structure of interrelated symptoms (Borsboom and Cramer, 2013). This approach allows for the identification of central (i.e., highly influential) indicators of psychopathology, and their structural relationship with other clusters of symptoms of a disorder. Symptoms in a network model are called nodes; associations between nodes are called edges (Epskamp and Fried, 2018). The associations or "edges" between nodes is assigned a weight representing the relative correlational strength and is displayed graphically by the line weight.

Network structure was estimated eliminating near-zero edge weights by estimating a penalized maximum likelihood solution based on the Extended Bayesian Information Criterion (EBIC; Foygel and Drton, 2010). This method of estimation is preferred as it nulls near-zero edge weights to allow for estimation and assessment of a more parsimonious network free of spurious correlations (Epskamp and Fried, 2018). Networks were undirected in estimation due to the cross-sectional nature of the study and structural hypotheses of the current study. Spearman's rank correlations were used within the polychoric matrix as symptom data was recorded on an ordinal scale.

The hierarchical network was estimated and assessed using the Exploratory Graph Analysis package ('EGAnet': Golino, 2023), and visualised using the 'qgraph' package (Epskamp et al., 2012) in R Studio (R Studio Team, 2020). This analytic technique aims to identify communities of symptoms/difficulties using algorithmic clustering of nodes (Golino and Epskamp, 2017). The hierarchical network structure was estimated to investigate structural representations of PTSD and CPTSD and model fit inspected using the Total Entropy Fit Index (TEFI), an indicator of fit for a correlational matrix that computes the distance in means between communities, and Generalized Total Entropy Fit Index (genTEFI), the sum of lower and higher order model communities' TEFI with lower values indicative lower multivariate disorder, and therefore of better model fit (Golino et al., 2021, 2024). Conventional model fit indices were additionally computed for network structures; the Comparative Fit Index (CFI), Tucker-Lewis Index (TLI), Root Mean Square Error of Approximation (RMSEA), and the Standardized Root Mean Square Residual (SRMR). Values considered indicative of acceptable model fit are ≥0.95 on the CFI and TLI, ≤0.06 RMSEA, and ≤0.08 SRMR (Hu and Bentler, 1999).

Detection of node community clustering was estimated using the Louvain algorithm, a method demonstrated to be robust in detection of both first-order and hierarchical network communities (Christensen, 2022; Jiménez et al., 2023). These analyses applied the highest modularity consensus method for identifying communities in first-order and hierarchical models. Community detection was validated using 1000 bootstrapped samples.

Finally, the stability of these networks was assessed using the bootstrap exploratory graph analysis ('bootEGA') and dimensional stability ('dimStability') functions with 1000 resamples. This method also for the assessment of stable replication of network structure across resampling (Christensen and Golino, 2021). Acceptable threshold for item-dimension replication suggested to be 0.70 (Christensen and Golino, 2021).

3. Results

3.1. Descriptive statistics

The study sample ($N = 2524$) was drawn from three African nations; Ghana ($n = 500$), Kenya ($n = 1006$), and Nigeria ($n = 1018$). The gender balance was approximately equal across the study sample (Male = 50.4 %), and the mean age was 30.75 ($SD = 8.93$). The majority were in a committed relationship (53.33 %), employed full- or part-time (55.54 %), and educated at college/university level (91.92 %). Full details of demographic characteristics for the study samples are available in Supplementary File 1.

The most commonly endorsed lifetime potentially traumatic experiences were; *Physical assault* ($n = 1307$, 51.78 %), *Transportation accident* ($n = 1068$, 42.31 %), and a *Serious accident at home or work* ($n = 752$, 29.79 %). The most common index (i.e. worst) traumatic event endorsed was experience of a *Transportation accident* ($n = 380$, 15.06 %), followed by *Physical assault* ($n = 302$, 11.97 %) and *Sexual assault* ($n = 243$, 9.63 %). Based on diagnostic screening criteria $n = 871$ (34.51 %) of the study sample met criteria for PTSD, and of these $n = 401$ (15.89 % of total sample) met criteria for CPTSD. Full details of trauma endorsements across the study same and country sub samples are available in Supplementary File 1.

3.2. Network analysis

Networks were estimated globally prior to hierarchical community detection as proposed in the current investigation. The global centrality estimates presented by Levin et al. (2021) also using these data were replicated (see Supplementary File 1). The most central indicators as determined by Expected Influence indices were: '*Feelings of failure*', '*Feeling distant or cut off from others*', and '*Internal avoidance*'. Given the similarity in network structure across samples identified in previous research (see Levin et al., 2021), hierarchical exploratory graph analyses were applied to the full sample ($N = 2524$).

3.2.1. Hierarchical network results

The hierarchical order network was estimated using 'EGAnet' (see Fig. 1). The overall model fit was favourable: the hierarchical network model produced acceptable CFI, TLI, RMSEA, and SRMR fit indices (see Table 2). Inspection of entropy fit indices revealed that the estimated hierarchical network produced a lower TEFI than the lower-order model (genTEFI = −6.424), indicating less disorganised and better model fit. This metric has been shown to perform favourably in differentiation between correlated traits and bifactor structures relative to traditional fit indices (Golino et al., 2024), and thus the hierarchical model was judged to provide optimal fit to these data.

Higher-order communities were identified each comprised of three grouped nodes: a PTSD community comprised of Re, Av, SoT, and a DSO community comprised of AD, NSC, and DR (see Fig. 1). Each of these higher-order community nodes loaded on to representative items in the first-order network structure. These communities aligned with ITQ symptom groupings with each community comprising two items aligned to each symptom domain, suggesting the structural validity of this measurement and conceptualisation of CPTSD. Results of replication analyses showed the higher-order PTSD community to be stability replicated in 100 % of samples, and the DSO community to be replicated in 57.7 % of bootstrapped samples.

Regarding lower-order communities; the majority (Re, Av, AD, and NSC) were found to be replicated in 100 % of samples, however stability was less favourable for SoT and DR (66.4 % and 87.1 % respectively). When item instability was inspected more closely it was found that *Hyperarousal* [p5] loaded on to the Av community in 29.7 % of replications, and *Exaggerated Startle* [p6] loaded on to the Re community in 23.6 % of replications. Among the DSO symptoms: *Feeling distant or cut off from others* [c5] and *Difficulties feeling close to others* [c6] were aligned with the AD community in 16.0 % of replications (see Supplementary File 1). As seen from edge weights in Fig. 1, the higher order AD node was positively associated with the higher order SoT node. In addition, the higher order DR node was positively associated with the higher order Av node. Full details of edge weights, i.e. associations, between nodes for network models are provided in Supplementary File 1.

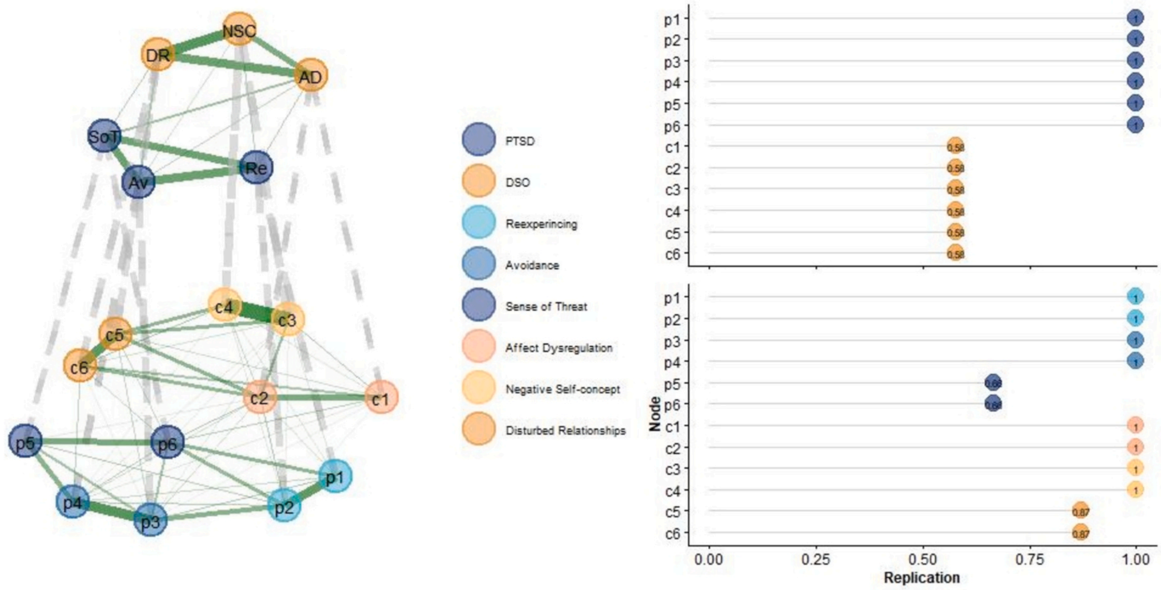

Fig. 1. Hierarchical network graph of ICD-11 CPTSD.

Table 2
Model fit indices for lower- and high-order network community structures.

	χ^2	df	CFI	TLI	RMSEA (90 % CI)	SRMR	TEFI
Lower-order	145.963***	39	0.999	0.998	0.033 (0.027–0.039)	0.025	5.572
Higher-order	258.641***	41	0.998	0.997	0.046 (0.041–0.051)	0.033	−11.996

Note: df = degrees of freedom, CFI = comparative fit index, TLI = Tucker–Lewis index, RMSEA = root mean square error of approximation, SRMR = Standardized Root Mean Square Residual, TEFI = Total Entropy Fit Index.
* $p < .05$, ** $p < .01$ *** $p < .001$.

4. Discussion

This is the first study that adopted hierarchical EGA in psychopathology to investigate the hierarchical network structures of ICD-11 CPTSD. Fit indices supported interpretation of the hierarchical network model providing most optimal fit to the data in line with Hypothesis 2. The PTSD and DSO communities previously identified in EGA of the ITQ (McElroy et al., 2019) were represented now by a more informative higher-order structure of PTSD and DSO each comprised of three grouped nodes, as theoretically expected. Moreover, our results echo investigations using factor analytic approaches suggesting that both a higher-order model comprised of PTSD and DSO structures, and first-order dimensions representing the six CPTSD symptom domains provide a valuable conceptualisation of this disorder (see Redican et al., 2021). However, the strength of the current study lies in the advantages of symptom network analysis which allows the complimentary investigation of the dynamics between the symptoms, in first and higher-order symptoms structure.

The higher-order structure identified is notably reminiscent with previous network analytic work that identified two community clustering in a first-order network (McElroy et al., 2019); suggesting that two communities exist comprising PTSD and DSO difficulties, however the addition of lower-order community clustering in six theoretically consistent symptom domains leads to superior fit. This provides an interesting consideration for the understanding of the dimensionality of CPTSD; while confirmatory factor analytic approaches may valuably assess data structures informed by theoretical perspectives, pre-assuming overall PTSD and DSO, the use of an EGA approach may offer an alternative and complementary model of addressing dimensionality (Golino and Demetriou, 2017; Golino and Epskamp, 2017).

Notably factor analytic evidence has suggested that the hierarchical structure of CPTSD is most often optimal in clinical samples, and the correlated first order factor model supported most frequently in population samples, however across studies both models are found to provide acceptable fit (Redican et al., 2021). This has been evident in treatment seeking samples (see Hyland et al., 2017b; Shevlin et al., 2017), and community samples (see Armour et al., 2021; Ben-Ezra et al., 2018); including in this African community sample (Owczarek et al., 2019). It has been hypothesised that differing coping styles, severity of symptomology, and trauma histories may drive this observation (Brewin et al., 2017; Mordeno et al., 2019). Further research is therefore needed to understand the roles of demographic factors and how these might affect the hierarchical network structure of CPTSD.

It should be noted that the higher-order PTSD community was replicated in 100 % of samples, and the DSO community to be replicated in 57.7 % of bootstrapped samples. Of those lower-order communities with lower replications results were observed for SoT and DR domains. *Hyperarousal* and *Exaggerated startle* difficulties also loaded on to the Av and Re communities respectively, potentially representing the correlation between avoidance and re-experiencing thought to represent a means of reducing threat-related distress arising from trauma memories (Hyland et al., 2023). Similarly, the finding that DR indicators also loaded on to the AD domain may be through the Cascade Model of CPTSD suggesting that complex trauma experiences contribute to the development of dysfunctional regulation and relational styles manifesting symptom-related distress (Maercker et al., 2022). The hierarchical network approach implemented offers unique advantage in the investigation of more granular association as demonstrated above.

In the higher-order network structure, the AD community node was associated with the SoT community node. The importance of this finding lies in the merging of AD nodes, which may represent contrasting strategies (such as hypo-activation, characterized by under-reaction or withdrawal, and hyper-activation, characterized by overreaction or heightened alertness). When these contrasting strategies are integrated into a higher-order factor, they still maintain a connection with the SoT domain. Indeed, experimental evidence has suggested that individuals with PTSD may transition rapidly between states of hyper- and hypo-activation in response to stressful stimuli (Korem et al., 2024). As such it should be considered that over time the correlation between these symptoms and domain associations may vary. Further time-series research is warranted to explore the potential dynamic network of CPTSD symptomology.

In addition, the higher order DR community was associated with the higher order Av factor. This compliments previous network analysis findings without this hierarchical approach (see McElroy et al., 2019), adding a potentially valuable layer of information in relation to individual symptom domain association. The clustering of lower-order symptoms structures consistent with theoretical expectations lend further support to the hypothesised structure of ICD-11 CPTSD. This finding also illustrates the value of hierarchical network analysis in revealing underlying structures or patterns that may not be apparent when examining disorders at a single level.

These findings may have implications for understanding therapeutic approaches, suggesting that treatments addressing these interconnected aspects could be more effective. Modular therapies such as Enhanced Skills Training in Affective and Interpersonal Regulation (ESTAIR; Karatzias et al., 2023; Karatzias and Cloitre, 2019) can allow for flexibility in targeting individually symptom clusters of CPTSD. Our results suggest that prioritising for treatment targeting the CPTSD clusters of sense of thereat and affect dysregulation might enhance treatment response rapidity.

The integration of dimensional and associative relationships between CPTSD symptoms fosters a more holistic view of the understanding of the disorder. Clinicians can consider not only individual symptoms but also their interconnectedness and the potential cascading effects within the hierarchical structure when devising treatment plans. Network Analysis is argued to be useful in treatment planning in this respect; allowing for the suggestion of causes and associations between pathologies (McNally, 2016). In this framework, central and bridging, i. e. highly connected, nodes are argued to be viable intervention targets as treatment of these may serve to deactivate networks of psychopathological symptoms (Castro et al., 2019).

These findings complement and extend those previous highlighting the most central symptoms of CPTSD in this study sample; feelings of worthlessness, affect dysregulation, and disturbed interpersonal relationships (Levin et al., 2021). The combination of the findings of the current study, and those previous, provide a strengthened evidence-base in support of intervention planning and development. Estimated in a hierarchical network structure the bridging connections are made more clear, highlighting detailed connectedness between symptom communities that may be used to formulate intervention for the most connected individual symptoms and for connected symptom communities. The Hierarchical Network approach is therefore presented as a potentially valuable and complimentary analytic framework for the investigation of psychopathology.

It is noted that reporting of traumatic stress pathology was relatively elevated in the current study sample with approximately one third of respondents meeting screening criteria for PTSD or CPTSD. It has been hypothesised that higher population rates of exposure to potentially traumatic events compared to general population samples drawn from other nations may contribute in part to these elevated rates of traumatic stress (Ben-Ezra et al., 2020). Further work is needed to empirically examine the utility of alternate conceptualisations of traumatic stress pathology in diverse samples. Understanding the first-order vs. hierarchical nature of symptoms in groups with varied symptomatic expression, and in longitudinal studies might aid in predicting potential symptom trajectories and designing monitoring protocols that consider symptom clusters and their evolution over time.

4.1. Strengths & limitations

This study has adopted a novel methodology to evaluate the dimensionality of ICD-11 CPTSD symptomology. The study encompasses an international sample, aligning with the cross-cultural validation goals outlined in ICD-11. It is important to note that even though each national sample was approximately a representative of the population with regard to age and gender, the current study's sample consisted predominantly of well-educated participants who may reside in urban and suburban areas, with better internet access, higher economic status, and most likely with higher proficiency in English. Even though the official language in the three countries is English and thus English is spoken by the majority of the population, there are multiple additional local dialects which we were unable to consider and which may have "westernised" the results to some degree. Furthermore, the cross-sectional nature of the data impedes directional assessment of network structures, emphasizing the need for future research to consider longitudinal and prospective measurements. This approach could offer insights into the temporal dynamics and evolution of CPTSD. There may also be concerns regarding the use of this emergent this approach overfitting the model, i. e. inadvertently capturing spurious association or noise in having communities identified at first- and higher-orders (Bonifay et al., 2017).

5. Conclusions

This study describes the first structural investigation of ICD-11 CPTSD using a hierarchical network approach. Results contribute to a novel and unified theory of CPTSD structural validity suggesting that dimensional networks comprising higher-order communities of nodes may offer a valid and useful conceptualisation of ICD-11 CPTSD. Further research is warranted to assess the reliability of these findings, and to investigate the utility of this hierarchical network approach to understanding psychopathology, and effectively planning treatment accordingly.

Supplementary data to this article can be found in Supplementary File 1, *Analyses R Markdown*, online at https://doi.org/10.1016/j.jad.2024.10.015.

CRediT authorship contribution statement

Martin Robinson: Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Yafit Levin:** Writing – review & editing, Methodology, Formal analysis, Data curation. **Philip Hyland:** Writing – review & editing, Conceptualization. **Thanos Karatzias:** Writing – review & editing. **Menachem Ben-Ezra:** Writing – review & editing, Investigation, Funding acquisition, Conceptualization.

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Declaration of competing interest

The authors have no competing interests to declare.

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